CONCRETE

ITS USES IN BUILDING

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ITS USES IN BUILDING FROM FOUNDATIONS TO FINISH

BY

THOMAS POTTER

THIRD EDITION, REVISED AND ENLARGED

With 138 Illustrations.

LONDON
B. T. BATSFORD, 94 HIGH HOLBORN
1908

Printed at THE DARIEN PRESS, *Edinburgh.*

PREFACE.

THE first edition of this book was published in 1877, the second in 1891. Seventeen years' further practical and continuous experience, and the many improvements in various ways that have taken place in connection with the use of concrete during that period, make a third edition necessary.

Numerous useful works on concrete have been published of late years, but dealing almost entirely with methods of and calculations for reinforcement. These do not convey the information so essential for the general use of concrete, and for many purposes connected with building for which it is so well adapted. Practical instructions are necessary to explain the methods of dealing with the material in building works, and reinforcement is not always necessary.

I am aware that the information contained in these pages does not in some instances fall in with the views of some practitioners. I can only say, with deference to the views of others, that what I have written—as the result of nearly forty years' experience—I believe to be substantially correct.

I have included in the book a history of concrete and its application, because, so far as I am aware, nothing of a similar nature has been published, except of a fragmentary character. I believe it will be both interesting and afford

means for obtaining some useful hints from what has been done, both in modern and early times. It will be found that concrete in the abstract, and many applications which are assumed to be of quite a novel character, bear out the old adage that there is nothing new under the sun.

THOMAS POTTER.

22 HAVELOCK ROAD, CROYDON,
June 1908.

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CONCRETE:

ITS USES IN BUILDING.

CHAPTER I.

HISTORY OF CONCRETE.

CONCRETE has been used for building purposes from time immemorial, although not applied in the way that is usual in this country now, but with similar results.

Fragments of concrete buildings have been found in Mexico and Peru belonging to prehistoric times. In the Italian colonies of Magna Græcia there is evidence that the ancient Greeks used it extensively, while the Romans employed it on a large scale both in this country and elsewhere. Professor Middleton said, many years since, that its use by the Romans could be traced as far back as 500 B.C., and that their method of using it for building purposes was very similar to ours at the present time, but almost entirely as a constructional material. The remains of walls of buildings existing at the present time show that the use of brick or stone facings was mostly the custom, and the concrete employed as a core between the inner and outer facings, or as a backing to walls faced on the side exposed to view. Probably the use of concrete is identical with the earliest period of employing quarried stone for building

walls when mortar was invented, and which would arise almost as a necessity.

The practice in many stone districts in this country is, and probably always has been where the thickness of walls permits, to face the latter with stone on both sides and to utilise the smaller stones not large enough for facing for the core, by bedding them in mortar, filling the interstices with the still smaller chippings and waste, and pouring in liquid grout of lime and sand until every crevice is filled. The whole in this way becomes a solid mass.

This simple process must inevitably have occurred to the earliest stone wall builders when lime was known, and the result was a concrete core, examples of which are to be found in many parts of the world.

A very old Lancashire proverb, which possibly dates from mediæval times, runs:—

> "A castle wall to be stout
> Must be full of mortar and grout."

Judging from the remains of Roman and Norman buildings in this country—Corfe, Rochester, Pevensey, and Richmond Castles, for instance—the method described must have been usually adopted. If the smaller rough stones to form a core were not available, then chippings were used instead, but the concrete remains of old castle walls are so homogeneous in character and the aggregate generally so considerable in size that the modern method of mixing the materials together on a platform and depositing them *en masse* between the wall facings could not have been the general practice in those days. When circumstances rendered facing with stone unnecessary, boards were used to form encasing panels, just as we do now.

From wall building to the construction of roofs, floors, stairs, &c., with concrete was a natural sequence. The concrete stairs at Colchester and Rochester Castles still show the marks of the encasing boards.

The great dome of the Pantheon, built by Agrippa

27 B.C., 142 feet diameter, with an opening 36 feet diameter in the centre at top, is concrete.

The House of the Vestals had an upper floor of concrete, 20 feet span and 14 inches thick, supported on corbels projecting from the walls, and in the Baths of Caracalla there are remains of extensive concrete vaults.

The foundations of Salisbury Cathedral, formed about 800 years since, are of concrete; the only remaining fragments of Old Sarum built by the Romans show evidence of its extensive use; Corfe Castle walls are largely composed of it; Reading Abbey walls were apparently faced with ashlar or squared blocks of stones on both sides, and the core or backing made of concrete, with the result that the stone appears to have perished, but the concrete, which was intended to play a secondary part, still remains; some portions of Rochester Castle walls are concrete, and, indeed, one has only to examine the remains of old buildings in Great Britain and other countries to discover that both Romans and Normans well understood its use and value.

Both had a thorough knowledge of mortar, as the walls of roofless castles and the remains of city walls in many parts of the country prove, although exposed to centuries of rain and frost, and which are apparently as strong now as when built. This is owing in a great measure to the interstices of the stonework being completely occupied by the grout used with the core filling, and to the custom of mixing pounded tiles or bricks with the lime to form mortar, which caused it to acquire increased hardness with time. Hydraulic —or water-resisting—lime was not always available where many ancient castles were built, but no doubt the builders were well aware that the addition of pounded tiles or bricks with a non-hydraulic or rich lime converted it into hydraulic mortar capable of resisting climatic changes.

It is singular that a knowledge of this peculiarity should apparently for a time have been lost. Smeaton, when experimenting with a view to adopting suitable materials

for building the Eddystone lighthouse, found that when the pure lime was extracted from lias limestone the residue was clay, and from this he made a brick which, when pounded and mixed with a non-hydraulic lime, entirely changed its character.

Palladio writes in 1570:—

"In ancient times coffer work was made by taking boards laid edgewise, according to the thickness of the walls, filling the space between them with cement and all sorts of small stones mingled together, and continued after this manner from course to course."

Alberti, another ancient architect, also wrote in 1485:—

"I have observed that in other places the ancients, who were wonderfully expert in making great works, followed different methods in filling up their foundations. In the sepulchre of Saint Antonini they filled them up with little pieces of very hard stones, each not bigger than a handful, over which they perfectly drowned the mortar. I have known other instances where the ancients have much the same sort of foundations, and structures too—of coarse gravel and common stones that they have picked by chance, and which lasted many ages."

Vitruvius writes in a very similar manner of the uses of concrete.

Fragments of apparently excellent concrete may be seen under a glass case in the Chapter House of Westminster Abbey, found under the paving of the tomb of Abbot Ware, who died in 1283.

Philibert de L'Orme, a French architect, writing in 1568, describes the usual custom at that period for making concrete as follows:—

"The excavations being made, whether for houses, harbours, bridges or buildings in a marshy soil, or even on land, and if being deep and wide, stones of a large size cannot be used for the foundations. The best and surest method is to prepare a mortar composed of quicklime recently burnt, mixed with river sand which contains a

quantity of pebbles of all sizes, provided the largest be not bigger than the fist or the size of an egg, and that the whole be interspersed with smaller pebbles and gravel, such as are usually found in rivers. This material moistened with mortar and mingled with lime serves both for mortar and stone, and mixed with a sufficient quantity of sand must be thrown at once into the excavation, without any labour from the mason's trowel. It is only necessary to dress it with a spade. Having thrown in a layer about half a foot in thickness, large single stones may also be thrown in and mixed here and there with it as may be convenient, but without touching each other; after this you will again throw upon them the mortar of pebbles and gravel as before done, and this must be repeated till the excavation is full, throwing the whole from above with all sorts of small pebbles. The composition thus executed hardens and solidifies so firmly in the foundations that, being heaped up in a mass and bound together, it becomes a uniform body or rock, such as nature forms, of a single block and so strong and hard that when dry it cannot be broken either by piles or any other instrument, nor can the pebbles be separated from it without breaking them to pieces."

In this country the use of concrete seems to have been almost forgotten or neglected for centuries, until about 1774, when Smeaton wrote about it, and practised with it. Other engineers interested themselves in connection with foundations—Rennie, Smirke, and Brunel among others—but in a general way its adoption was slow.

Semple, an engineer, used it for the foundations of a bridge over the Liffey, in 1753, and writing about it at the time said:—

"There are three different methods for making use of lime in such a work as this; one is to mix the roach lime (made liquid) with its proportion of sand and small stones in such a manner as may clothe every stone and particle of sand with it; the second, to slack and turn them all up

together like mortar; the third, to lay each of the three, as it were, in thin layers, still observing the same proportion. Take which of these methods you please, provided the roach lime be, however, carefully and judiciously mixed with the stones and sand, for if these materials are not equally mixed, how can you expect them to petrify and unite into one solid mass? But if they are properly mixed together, the whole stuffing of the coffer will actually petrify, and become one solid compact substance, as hard and as closely united together as if the same was in one block or rock, and it will be many hundreds of years before the coffer (being in the water) will be in the least decayed."

Mr Godwin, a former editor of the *Builder*, obtained a prize offered by the Royal Institute of British Architects in 1836 for the best essay on concrete, and this essay was undoubtedly the means of directing public attention to its value. For building purposes, foundations included, concrete still made but little headway for years afterward; this was to be accounted for, in a measure, because the only suitable materials available in this country of a cementitious nature were Roman cement and hydraulic lime; the former was too costly and set too quick, and the latter was obtainable in only a comparative limited area, while land carriage was in very many places a costly item; suitable machinery for grinding lime, moreover, did not exist to any extent, two great drawbacks to anything like a general adoption of concrete, even for foundations, but with the introduction of railways and of steam machinery enabling lime to be finely ground at almost a nominal cost it began to make headway. But it received so little attention that in many instances it only occupied three or four lines of a building specification, and these the reproduction of some antiquated description of dealing with it. As an instance of this, in "Bartholomew's Specification for Practical Architecture," published in 1886, which professed to be a textbook of specifications, we find that out of more than 400 pages describing how bricklayers', carpenters', and every

other kind of building work should be performed, less than half a page is devoted to concrete, while for concrete floors three lines are considered sufficient, as follows:—"A concrete floor to be formed for the beer and wine cellars, six inches thick, well beaten down, and smoothed at top." Nothing could be more brief or more uncertain as to what was intended, or as a guide for a specification could be more misleading.

General Pasley in his treatise on limes and cements, published in 1847, says:—

"Concrete is a recent improvement first adopted by Sir Robert Smirke with success in the foundations of the Penitentiary at Millbank, where the soil chiefly of peat moss was soft, to a great extent. The origin of its use arose in this way; in excavating for one of the piers of Waterloo Bridge the workmen had a good deal of difficulty, owing to the very compact state of the gravel forming the bed of the river, which everywhere else had been found perfectly loose. The effect had been produced by the accidental sinking of a bargeload of lime over the spot some time before, which had cemented the gravel into a solid mass, resembling the calcareous conglomerates of nature which are gradually formed by a similar process. Mr Rennie, the engineer, having mentioned the circumstance to Sir Robert Smirke, the latter with great judgment availed himself of the hint, and subsequently used concrete in all his foundations, none of which have ever been known to fail."

This statement is, however, scarcely correct, as a report by Messrs Rennie, Lewis, Cockerell, and Brown, dated January 1813, recommended concrete foundations for Millbank, while Sir Robert Smirke was not consulted in the matter until 1817. It seems somewhat remarkable that General Pasley was conducting a series of experiments with limes and cements at Chatham, within a mile of one of the finest specimens of Roman concrete—Rochester Castle—without realising what a valuable factor in build-

ing construction was practically waiting to be developed, and with a knowledge that the castle had been given to a builder to clear away, but who, luckily, gave the job up in despair by reason of the strength of the concrete core.

It is strange how soon processes when they go out of use for a time are forgotten. In no instance is this more apparent than in the use of concrete. A London architect, writing to the *Builder* in 1848, says he has used concrete for foundations of buildings in London, but in the provinces he is unable to, as he can find no one who knows anything concerning it. General Pasley writes in 1847 that a Mr Thomas Cooper had used lime concrete for the formation of a sea-wall at the east cliff, Brighton, some years previous, and that to the best of his belief it was the first application of concrete other than for foundations.

CHAPTER II.

AGGREGATES.

CONCRETE, in an ordinary way, is a mixture of two materials, known as the "aggregate" and the "matrice," two words not very suggestive as to meaning, but accepted for want of others more suitable, and which appear to have been first used by Mr Henry Reid in his book on "Concrete" published in 1869. The aggregate is any reasonably hard material that can be obtained of a proper consistency and suitable size, or easily convertible to a suitable size, and for which the matrice—usually lime or Portland cement—has an affinity. Aggregates should possess cohesiveness in conjunction with the matrice, and a capacity for resisting compressive stress. More or less fitting aggregates are to be found in most localities, and as a result those which can be procured locally are usually selected; but discrimination is necessary in this direction, for there is a difference in the character of materials that pass by the same name. A specification may describe, for instance, that the aggregate is to be clean pit or river gravel to be obtained locally, and this description may lead to difficulties, for it may be clean in a sense, but mixed with clay, excellent in its way for garden paths and the like but totally unsuitable for concrete. Nor does it follow that an aggregate which is well adapted for one purpose is equally so for others. For instance, Thames ballast is an excellent aggregate for concrete in foundations, but one of the worst for suspended floors, by reason of its weight and inability to withstand the effects of fire. This applies also

to pit gravel, crushed flints from a chalk subsoil, and most quarry stones. But whatever the nature of the aggregate, it should possess the following qualifications:—It should be angular in form, that its particles may interlock with each other and form a homogeneous mass, and this is not possible unless it consists of many intermediate sizes from that of coarse sand to the largest permissible, and which depends upon the purpose the concrete is for, as in its soft state it will adjust itself to form a homogeneous mass much more readily in a wide foundation or thick wall, than it will in a narrow foundation or thin wall, enabling a proportion of the aggregate to be much larger in the former case than in the latter. The best shape for an aggregate may be better described, perhaps, as cubes of varying sizes, with all their angles and corners knocked off. The worst possible form for an aggregate is where it is comparatively large and uniform in size, or flaky, such for instance as stone chippings, or old bricks broken with hand hammers—the latter a usual material in many places. Concrete made with an aggregate of this kind is similar to a honeycomb, and the greater portion of the matrice is rendered useless.

To avoid this, we sometimes read that the aggregate is to be composed of, say, five parts of broken bricks, three parts of sand, and one of cement, the sand being necessary to fill up the interstices in the bulk of the aggregate, which it probably does; but Mr Grant's experiments for the Metropolitan Board of Works conclusively proved that when one part of cement is mixed with three parts of Thames sand it forms a mortar 33 per cent. only of the strength of neat cement. This conclusively proves that, although a proportion of coarse sand is necessary to obtain perfect homogeneity, no more than is actually necessary for the purpose should be employed. This condition, however, applies only where Portland cement is the matrice; when hydraulic-ground lime is used the reverse is the case. General Pasley and others found from actual experiments

that it reaches its maximum strength when mixed with two or three parts of sand. If the aggregate is uniformly small, the result, where cement is the matrice, is a weak mortar instead of concrete. If a large number of small materials require to be cemented together to form a block of given dimensions, it is self-evident that the cement must have a much larger superficial area to cover than if they were larger. It may be that where the aggregate can only be obtained of small size, hydraulic-ground lime can be used with advantage, both as regards cost and strength, in places like foundations for walls. The aggregate should be clean. This is of great importance, and easily determined if a suspicious aggregate is washed in a bucket of water and well stirred. If some test blocks of cement are made with this water and others with quite clean water, both from the same sample of cement, and tested under equal conditions, no further evidence of the necessity will be required. A good illustration of the value of a clean aggregate possessing a diversity of size can be seen any day in the streets of London where the roadways are being broken up for gas or water pipe repairs. The concrete below the paving is Thames ballast, and although no great exactitude or care is usually apparent in the mixing and otherwise, three or four men with sledge hammers and steel wedges remove with difficulty, and after a deal of pounding, fragments of the concrete which have the tenacity of solid rock. Thames ballast is not quite an ideal aggregate; its particles are rounded by attrition and not so angular as desirable, but it is clean and its proportions well distributed.

There is another factor, however, and this is that quickly after the concrete is deposited in place, wood blocks, or asphalt, is laid thereon, which effectually excludes the air necessary for hardening, and as the retardation of setting increases the ultimate strength, and the only air that can reach it is from the soil beneath—*i.e.*, ground air—it is possibly years before the latter occurs.

In many aggregates, more especially those that have passed through fire, such as boiler ashes, crushed brick rubbish, pottery, &c., there is usually a film of fine dust which clings to the particles and can only be eliminated by washing. This is very seldom done, but where circumstances permit the percentage of gain in strength arising therefrom is of greater value than the extra cost of labour. An illustration of this may be found in smiths' ashes, which contain a large amount of a dusty element, and particles of unburnt coal. Mr Grant made a number of experiments to ascertain the comparative value of various sands when used to make cement mortar, with the result that smiths' ashes mortar was only 25 per cent. of the strength of mortar made with sand from burnt clay ballast, 50 per cent. from a clean pit sand and sea sand, and 33 per cent. from Portland stone ground to sand. Another result of these experiments was that coarse sand invariably gave better results than fine.

The materials in common use more or less suitable as aggregates are Thames and other river gravel, pit gravel, sea beach or shingle, stone chippings, flints, débris from brickyards and potteries, materials from walls of old buildings, blast furnace slag (the residue in smelting iron ore), breeze from gas works, boiler and furnace ashes, burnt clay, and local products of a similar character. If the smaller element predominates, a portion should be screened therefrom to bring it within the description previously given; on the other hand, if some portions are too large, they should also be screened out, broken, or otherwise removed. If generally the material is too big, it should be crushed by a Blake Marsden or other suitable machine. This is usual with slag, débris from old buildings, brickfields and potteries, and occasionally with quarry refuse. Materials crushed in this way possess a suitable consistency for an aggregate without any addition thereto or subtraction therefrom, but I have, in cases where sand was wanted and none available, had the crusher set fine, to produce a

larger proportion of the sandy element than was necessary, to enable a portion to be abstracted for mortar making.

With regard to the extreme size of the aggregate, no hard and fast rule can be made. It is one of the numerous matters in connection with concrete that cannot be satisfactorily standardised. I am aware that this is sometimes disputed. The R.I.B.A. Committee says, "The maximum allowable size is usually ¾ inch," and also, "The sand should be separated from the gravel or broken stone by screening before the materials are measured."

If these suggestions were made compulsory, the cost of reducing a larger size aggregate to pass a ¾-inch screen, and screening the sand out of the aggregate, measuring the proportion specified, and remixing it, would add considerably to the cost.

For a concrete wall or floor, 6 inches thick, obviously no portion of the aggregate should be larger—under ordinary circumstances—than would pass an inch and a half cross mesh sieve; on the other hand, for foundations 4 feet to 5 feet wide, the larger the better if homogeneity can be secured; and a knowledge of this is only arrived at by some experience. The surface appearance of concrete is not direct evidence of want of homogeneity; it may appear rough, and suggestive of unsoundness below the surface; but if a deep cut is made across the trench, lintel, or wall after it is hard enough to permit this without fracture, it will possibly be found of quite a different character to that which its surface appearance indicates.

Where the aggregate requires crushing, my practice usually is to set the crusher to a 2-inch gauge for walls 9 inches in thickness, and 2½ inches for 12 inches and over—that is, the greatest diameter of the aggregate shall not exceed 2, and 2½ inches respectively, the remainder in the process of crushing being graded down to the size of coarse sand. I am aware that these dimensions are in excess of the general practice, but I am satisfied, and have proved

that far better results are obtained in this way. The strength of the aggregate is often sacrificed with a view of obtaining a better surface appearance.

Mr Charles F. Marsh, in *Concrete and Constructional Engineering* for September 1907, writes of a series of experiments made by Mr Feret, an American engineer, and published in the *Proceedings of the American Society of Civil Engineers*, vol. xxxiii., with a view of ascertaining the laws of proportioning concrete, and which corroborate this view, for Mr Feret says: "To obtain the greatest resistance it is advisable to increase as much as possible the size of the aggregate, and diminish the finer grains. The largest aggregate makes the densest concrete; an aggregate having a maximum diameter of 2¼ inches proved to be denser than an aggregate of 1 inch maximum diameter." This result is just the reverse to what has been taken for granted ever since concrete has come into general use. Again, "Permeability is less as the maximum size of the aggregate is greater; concrete with a maximum size aggregate of 2¼ inches diameter, is in general less permeable than with a 1 inch maximum diameter, and 1 inch maximum less than ½ inch." These results were arrived at from a large number of experiments, and are opposed to all theory, another proof that theoretical deductions in matters dealing with concrete must be received with caution.

It is generally assumed that a moderately porous aggregate will best ensure the cohesion of its particles, and if capable of resisting a heavy compressive stress should be the best. Major-General Pasley made some experiments in this direction by cementing together blocks of various materials and ascertaining the tensile strain which would separate them. The blocks, measuring 10 inches by 4 inches by 4 inches, were cemented together with Roman cement, and tested at the end of eleven days, with the following result:—

EXPERIMENT No. 1.

	Pounds.
Bricks - - - - - - - - - -	1,359
Kentish rag stone - - - - - - -	1,349
Bath stone - - - - - - - -	1,100
Cornish granite, polished - - - - - -	928
Do. do. not polished - - - - -	900
Portland stone - - - - - - - -	856
Craigleith stone - - - - - - -	855
Yorkshire stone - - - - - - -	823

The result differs, however, a good deal from experiments made by Mr Grant for the purpose of ascertaining the best aggregates for concrete for the Thames Embankment and their various compressive strengths. Cohesive strength and compressive resistance do not always go together, as the following experiments for ascertaining the crushing stress, when compared with No. 1, will prove. The blocks were 6-inch cubes; they were moulded on 6th November 1867, and tested 6th November 1868; the proportion was one part of Portland cement to eight parts of the respective aggregates of a suitable consistency, and both by measure, the blocks being compressed.

EXPERIMENT No. 2.

	Kept in Air.	Kept in Water.
	Tons.	Tons.
Portland stone - - - -	33	29
Pottery - - - - -	22	23
Slag - - - - - -	19½	13½
Granite - - - - -	19½	16
Glass - - - - -	18	17½
Flints - - - - -	17½	20
Ballast - - - - -	13½	13½

Where the materials were not compressed the result was as follows:—

EXPERIMENT No. 3.

	Kept in Air.	Kept in Water.
	Tons.	Tons.
Portland stone - - - - -	24½	19½
Pottery - - - - -	18	18
Granite - - - - -	14½	13½
Flints - - - - -	14	12½
Glass - - - - -	13½	11½
Slag - - - - - -	14	9½
Ballast - - - - -	12½	11

These experiments show that where compression, or a gentle impingement of the concrete, can be practised the strength is considerably increased; but this is not always possible.

Other experiments made by Mr Grant proved that certain concrete materials increased in strength when the proportion of cement was increased, much more rapid than others. For instance, and in the following order, 25 per cent. more cement increased the strength of the concrete 50 per cent. and over when made from (1) granite, (2) ballast, (3) slag. Portland stone chippings nearly always stood first in the order of merit when tested for compressive strength in the case of many hundred experiments made by Mr Grant; but one result of Nos. 2 and 3 experiments is puzzling—that glass should, as an aggregate, be nearly as strong as granite; the glass used was crushed bottle glass.

There is little or no porosity or capacity for absorption in glass to afford a key for the cement. On one occasion being desirous of making some cement slabs which should be quite true and smooth, I used a number of plate-glass squares as moulds or frames for the purpose, and, although their surfaces were oiled to prevent adhesion it was impossible to liberate the cement castings; both the latter and the glass moulds had to be broken up.

Major-General Pasley found a similar peculiarity with

hard stone and marbles; when their surfaces were worked perfectly true and smooth and cemented together they resisted a pulling strain with a view to separate them equal to similar stones and marbles with their surfaces roughened or jagged to give a key for the cement, as is generally practised in masonry.

Another series of experiments made by Mr Grant was to ascertain the proportionate rate neat cement, and half cement and half sand increased in strength, with the result that each reached its maximum strength in two years, but not before; and we may reasonably assume, therefore, that concrete does not attain its full strength until the cement has also, and this may not happen in practice until a much longer period than with test blocks; for instance, when it is of unusual thickness and air permeates but slowly, or the aggregate is of a non-porous character. I remember an occasion when a newly built concrete wall, 4 feet thick, had to be removed; the outside portion was detached with some difficulty, but as the centre was approached it became softer, and at that point could be broken apart with the hand, although it had been in place over a month.

Mr Grant on no occasion appears to have experimented with boiler ashes, furnace clinker, or coke breeze. Their appearance is not in their favour as aggregates; coke breeze more especially is somewhat small and soft, and its particles not sufficiently diverse in size to expect good results therefrom. Until recent years, and when it began to take the place of Thames ballast for floors, it was considered a waste product which the gas companies were glad to give away, and when this did not happen, it was taken away in vessels and dumped down wherever dumping ground was available, or pitched into the sea. Messrs Kirkaldy & Son have, however, quite changed the opinion of its value as an aggregate; they made experiments for the West Ham Corporation a few years since with coke breeze as an aggregate, and for comparison with stock brickwork in mortar, with the following result:—

EXPERIMENT No. 4.

		Cracked Slightly.		Crushed.	
		Lbs. per Sq. In.	Tons per Sq. Ft.	Lbs. per Sq. In.	Tons per Sq. Ft.
2895	Brick pier A, 18 in. by 18 in. by six courses high, stock bricks set in blue lias lime mortar -	730	46.9	730	46.9
2896	Brick pier B, 18 in. by 18 in. by six courses high, Harold Wood bricks set in blue lias lime mortar - - - - -	1,099	70.7	1,168	75.1
2897	Concrete block C, 18 in. by 18 in. by 18 in., 6 parts coke breeze, 1 part Portland cement, 2½ years old - - - -	2,037	131.0	2,037	131.0

This is an extraordinary result so far as coke breeze is concerned, and which about equals the crushing strength of gault bricks.

Tests made at the Watertown Arsenal for the American Government in 1904, with one of cement, two of sand, and four of furnace ashes—practically one to six—at seven months old, gave respectively 2,500 and 2,600 pounds per inch crushing strength, which is higher than Messrs Kirkaldy & Son's test.

The practice in the United States with the view of simplifying the method of describing the proportion of the materials is to give the cement first, then the sand, and next the aggregate; thus the test just given would read 1—2—4, and if no sand was used, then 1—4. The practice is becoming general in this country.

There is a confusion of ideas and nomenclature with regard to the product arising from the consumption of coal. Here we call it ashes, cinders, clinker, and breeze.

The siftings from ash-holes is used for burning bricks in clamps, and is also called "breeze"; ashes is the general

name given to the residue of almost every kind of fuel beside coals; cinders is generally associated with the remains of fires in domestic buildings; clinker is the residue of coal which has partially calcined or fused from high temperature; and coke breeze, sometimes called coke ashes, is the finer part of the coke from gas retorts, but as it is now customary to re-use the best portions of the coke to assist in heating the retorts, and the remainder that will not pass a half-inch screen, for conservatory boilers and similar objects, the residue is too fine for general purposes. The portion that drops through the bars during the heating of the retorts is called pan breeze, and being thoroughly burnt is the best for concrete.

The official Report of the United States Government Engineer with regard to the Baltimore fire states: "Coke breeze is safe when subject to intelligent supervision; when made from proper materials it is doubtful whether even brickwork is much superior to it for fire-resisting qualities, and other things being equal there is nothing superior to it for lightness."

Clinker, if reduced to a suitable consistency, makes a good aggregate, but is sometimes of a honeycomb description which is objectionable, and when broken or crushed contains too much fine dusty material which is better washed out. Clinker from destructor works is a good deal used for paving slabs, with and without a face of crushed granite chips.

Different kinds of coal produce different varieties of breeze and ashes; some are quite unsuitable for an aggregate.

The cinders or ashes from furnaces sometimes contain sulphur, which, if in excess, will cause expansion of the concrete. The only remedy, so far as I know, is to aerate it by allowing it to be exposed to the atmosphere. This is, however, very seldom possible, especially in large towns. Where the amount of sulphur is not very large, it has been found, from experiments made in America, that the lime in

the cement neutralises the bad effects it might cause if in excess. There have been cases in this country where expansion and serious injury to concrete has resulted from sulphur in the aggregate.

Mr Grant found that at the end of a year blocks of concrete, 12 by 12 by 12 inches, made with one part of cement to six parts of Thames ballast, broke under a compressive strain of 56 tons; one of blue lias lime and six of ballast, 6 tons.

The ratio of the increase in the strength of concrete can only be arrived at, so far as I can ascertain, by a knowledge of the increase of the tensile strength of cement, in the absence of published records relative thereto. Mr Grant made ten experiments with neat cement, and ten with one of cement to one of sand, with the following result:—

EXPERIMENT NO. 5.

Age.	Neat cement $2\frac{1}{4}$ sq. in.	1 cement, 1 sand, $2\frac{1}{4}$ sq. in.
	lbs.	lbs.
7 days - - -	817	353
3 months - -	1,055	547
6 " - -	1,176	640
9 " - -	1,219	692
12 " - -	1,229	716
2 years - - -	1,324	790
4 " - - -	1,312	818
6 " - - -	1,308	819
7 " - - -	1,327	863

But the ratio of increase in the strength of concrete may possibly be more correctly judged when the sand is in larger proportion to the cement. Mr Grant made 960 experiments in the years 1862-3 with one part of cement to three parts of sand, the average result being:—

EXPERIMENT No. 6.

Age.	Per cent. of Strength of Neat Cement.
1 week	6.07
1 month	8.53
3 months	15.13
6 ,,	23.74
12 ,,	29.90

We may conclude from these and experiments of a similar character that Portland cement concrete at one month old does not reach approximately more than 33 per cent. of its ultimate strength, and at three months 50 per cent. The nature of the aggregate and the quality of the cement will obviously influence the result to a large extent, but the assumption is that both are of the best description.

Another experiment made with one part of cement to six parts of various aggregates, tested at the end of a year, 6 inch cubes compressed, gave the following results :—

EXPERIMENT No. 7.

Proportion.	Weight in lbs.			Weight of each Block in lbs.		Crushed at Tons.		Remarks.
	Cement.	Sand.	Water.	Kept in Air.	Kept in Water.	Air.	Water.	
6 to 1	2.26	15.31	1.00	17.90	18.60	20.40	19.60	Ballast
	2.40	12.80	1.45	16.90	17.67	40.60	34.50	Portland stone
	2.31	14.56	1.30	18.53	18.88	30.50	27.00	Granite
	2.16	13.33	1.75	16.10	17.50	28.80	26.50	Pottery
	2.11	12.29	1.60	15.08	16.61	23.00	23.50	Slag
	2.03	13.91	1.45	16.50	17.65	20.50	24.00	Flints
	2.37	15.51	1.30	18.50	19.25	28.00	23.00	Glass

From this we gather that the strength of concrete—up to certain limits—does not decrease *pro rata* to the amount of cement employed.

Tests for floors of concrete are specified in many cases at the present time to be made at a month, when they are supposed not only to stand the maximum stress, but a factor of safety in addition. It is a question whether many floors which have undergone this test have not been permanently weakened through over-strain. No floor should be fully tested under three months, and if it will stand the specified test then it will undoubtedly be 30 to 50 per cent. stronger in course of time, always assuming that the best and proper materials are employed. The common assumption appears to be that concrete must possess a large margin of strength over and above all possible requirements, in case it should diminish hereafter; whereas—always again assuming that materials and workmanship are good—it is about the only material in a building that goes on increasing in strength for years.

It is worth noting that certain aggregates allow a smaller proportion of cement to be used therewith than others, without a corresponding diminution of crushing strength, as Mr Grant proved by the following experiment, in which the proportion was one of Portland cement to ten parts of various aggregates, the blocks being 12-inch cubes, and tested at the end of a year:—

EXPERIMENT NO. 8.

Crushed at Tons.		Aggregates 10 to 1.
Air.	Water.	
48½	48	Ballast
50	60½	Granite
53	75	Glass
60	52	Slag
72½	78	Portland stone
70	98	Flints
90	100	Pottery

This experiment proves that flints make concrete at one

to ten nearly equal in strength to pottery, while glass is superior to slag.

The result of the above tests, which were the average of a large number of experiments, somewhat upsets previous experiments and all theory as to the strength of concrete made with different aggregates, for flint takes nearly the top place, Portland stone the third and but little superior to glass, while Thames ballast comes last.

Flint surfaces are of a glassy, impervious nature, and this experiment (No. 8) tends to prove that aggregates of a non-absorbent character make better concrete when the proportion of cement is low, than pervious ones. Flints, whether obtained from chalk strata or picked from the surface of agricultural lands having a chalk subsoil, should be washed and broken with a crusher—hand-breaking is quite useless for the purpose—and in this way an aggregate of a suitable nature and consistency is obtained without the admixture of any other materials; but the washing is better and more quickly performed after they are crushed, as the clay, marl, or chalk which adheres thereto is broken up into minute particles and much more readily got rid of, and the washing is more easily and economically performed on the mixing board, laid to a slight inclination, at the time the concrete is required. If the inclination is too great, the sandy element is carried away with the water; the boards should be adjusted to avoid this. (See Chapter IV.)

Beach gravel, or shingle and sand makes good concrete, for although uniform in size it is quite clean; the objection is that the salt it contains creates dampness, but the evidence is not conclusive on this point.

River gravel, when obtained from sluggish streams, has often fine muddy clay, washed in from the banks, attached thereto. This should also be eliminated by washing. Thames ballast is not always of one quality, as every London builder knows; it depends upon what part of the river it is obtained from.

Ashes from locomotive and other furnaces generally

make excellent aggregates as before stated, if not intermixed with engine-room sweepings, oily cotton waste, and dusty coal.

Clay, if thoroughly and uniformly burnt, is a good aggregate, but much depends upon the quality of the clay and the skill of the burner. It is one of those aggregates that require washing, as it is as a rule covered with a film of impalpable dust, and has to be broken or screened to a suitable size.

Relative to the cost of burning clay for an aggregate and the amount of water required for mixing concrete for walls—and where water is not abundant it is a matter of some consideration—Mr Homersham, C.E., in the *Journal of the Society of Arts*, says: "The minimum cost of burning ballast when clay fit for the purpose is found on the site of the works, may be put down at 3s. per cubic yard, including the cost of labour in sifting and washing, but not of providing the necessary quantity of water. The quantity of water required for washing and soaking burnt ballast is about 20 gallons per cubic yard, or a ton weight per rod. One half that quantity will suffice for washing good gravel, containing the proper proportion of clean, sharp, silicious sand. The quantity of water requisite for gauging cement is about 3 gallons per bushel of Portland cement, and 1 gallon per bushel of damp sand."

Old bricks from buildings in course of demolition make good concrete if broken with a crusher, but not if hand-broken. They should be roughly cleaned of old mortar—plastering mortar especially—while, if smoky and soot-laden, they should only be used in foundations. If used for walls, floors, or ceilings where the latter are formed by plastering direct on the concrete, stains will inevitably appear in course of time.

Old tiles, slates, and similar materials are unfit for an aggregate; they are unshapable and impregnated with smoke and impurities.

Chalk from the bottom stratum makes a fairly good

aggregate; the upper or soft stratum is of too soft a nature, but I built cottages therewith many years since, two stories high, having concrete upper floors, the walls 12 inches thick, which are and always have been quite dry, and left nothing to be desired. On one occasion I erected a specimen wall of soft chalk concrete, 4 feet in height and 9 inches in thickness, in the shape of a right angle on plan, measuring 5 feet each way, the concrete being one to seven. The chalk was screened through a 2-inch mesh sieve, and the portion that passed through a ⅜-inch mesh abstracted, and a coarse sand from crushed brickyard débris substituted. At the end of six months a chain was attached to one side at a point half-way in a straight line from the angle; a powerful cart horse was unable to pull it asunder. The weather had no effect on it, although not cemented on the face or covered on the top or otherwise protected, and after a year had elapsed it was broken down with sledge hammers. Blocks of chalk lying alongside were reduced to powder by the winter's frost, but blocks of chalk concrete were unaffected thereby. The cement appeared to have permeated the chalk and rendered it frost-proof. As an excellent material for building walls of military huts, &c., for the camp on Salisbury Plain, chalk was available everywhere in that district; walls could have been erected cheaply and by the military encamped there, and would have been warm and dry, instead of which cold and unsanitary iron and match-board structures were erected in almost endless number.

Specifications often describe aggregates to be composed of different materials in certain proportions, such, for instance, as five parts of clinker or broken-brick débris and two parts of sand or coke breeze; but the object is not clear. We seldom hear of cement mortar being made with cement and two different kinds of sand. In my experience the best aggregates are those in which the material is of one description throughout; if however Thames or other sand is added through an insufficiency of the

smaller element, it is a different matter, and cannot perhaps be avoided.

Many failures with concrete walls have taken place from causes unknown at the time. Slag, unless it has been allowed time for aeration by exposure to the atmosphere for a year at least to get rid of the sulphur it contains will disintegrate the concrete; failures have happened from using slag not sufficiently aerated, otherwise it is one of the best of aggregates.

Aggregates by rail have been conveyed in trucks previously used for the conveyance of lime, portions of which have got intermixed therewith, and, being unnoticed, have caused the concrete to blow or burst. This is not of frequent occurrence but has happened. The aggregate should not be deposited near a lime shed, nor where plasterers are running lime for plastering, as pieces of unslaked lime or lime core may inadvertently find their way among the concrete material. Numerous failures have occurred through pieces of lias limestone having passed through the furnaces of locomotives and got mixed with the ashes which were afterwards used for making concrete. It is the practice on railways to give the drivers gratuities when the consumption of coal is below or not above the average, and where lines pass through lias limestone districts the drivers have found that lumps of limestone, when mixed with the coal, economise the latter. I have seen a large flight of concrete stairs, and floors completely wrecked as a result.

Thames ballast and sand often contain pieces of coal which may have been thrown overboard, or in some other way got mixed therewith. It used to be thought that the coal expanded and burst the concrete, but late trials do not confirm this view.

In constructing the Harrisburg sewer in the United States, the river sand contained a good deal of fine coal, and a series of tests were made to ascertain what effect it had on the cement mortar. The coal was screened, only

that passing a No. 10 B.W.G. sieve and retained on a No. 24 being used. The test briquettes were made up of one part of Portland cement to three parts of sand, the sand containing varying percentages of coal from 0 to 100 per cent. It was found that there was no apparent decrease in strength when from 0 to 28 per cent. of coal was mixed with the sand, but there was then a gradual diminution in strength as more coal up to 100 per cent. was added. The final strength for 100 per cent. of coal was about one-fifth of the strength of clean sand. It follows therefore that coal, if not positively harmful when mixed with an aggregate, should be avoided as far as practicable. Concrete workmen believe that it tends to swell and burst the concrete, but I have never seen evidence of this.

Obviously, aggregates for floors and walls—the former more especially—should be fire-resisting to a high degree, and the best fire-resisting aggregates are those which have passed through fire or have withstood a great heat without disintegration, such as slag, furnace ashes, coke breeze, clinker, brick and tile yard débris, and burnt-clay ballast. Some of the floors tested for fire-resistance by the British Fire Prevention Committee had Thames sand mixed with otherwise good fire-resisting materials. Thames sand being the finer portion of flints formed by attrition is a bad material to withstand fire, and certain floors were as a result less successful than probably they otherwise would have been. (See Chapter XIV.)

CHAPTER III.

MATRICES.

CONCRETE matrices hitherto available have been lime,—plaster (commonly called plaster of Paris), Roman, selenitic, and Portland cements.

Until quite modern times lime was nearly the only material employed for a matrice. The white or chalk lime made from the upper chalk strata is much too weak for the purpose. The grey stone lime—so-called—made from the lower chalk strata is stronger and to some extent hydraulic, and until the advent of railways was almost the only lime used in and around London for building purposes and concrete. But the blue lias is far more valuable as a matrice, both as regards strength and hydraulicity, that is, the property of setting in water equally as well as in air, and of remaining unaffected by water.

EXPERIMENT NO. 9.

6 Parts of Gravel to 1 of a Matrice.	Lowest.	Highest.
Grey lime concrete - - -	1	1
Selenitic grey lime concrete - -	1.82	1.82
Blue lias lime concrete - - -	1.12	2.26
Selenitic lias lime concrete - -	1.69	3.64
Selenitic common lime concrete -	2.61	3.34

Mr Grant, in his valuable series of experiments made for the Metropolitan Board of Works between 1860-70, gives the result of the crushing strength of ten 6-inch cubes

of various kinds of limes, all proportioned by volume and all tested at the end of twelve months. The grey stone lime is taken as unity, the other figures representing the greater proportionate strength.

Mr Grant made another series of experiments to test the compressive value of limes at twelve months old, the blocks measuring 6 by 6 inches, with the following result :—

EXPERIMENT NO. 10.

8 of Gravel to 1 of the Matrice.	Lowest.	Highest.
Grey lime concrete	1	1
Selenitic grey lime concrete	1.66	1.66
Blue lias lime concrete	2.33	2.41
Selenitic blue lias lime concrete	4.27	7.44
Selenitic common lime concrete	3.32	4.74

The great diversity of strength shown by these experiments is ample evidence of the unreliability of compressive tests for lime. The hydraulicity of blue lias lime is to be accounted for by reason of the clay, chemically known as "alumina" and "silica," contained in the lias limestone, the proportion of the clay in the Lyme Regis stone, according to Mr Henry Reid, being 17 per cent. Not less than 10 per cent. will, however, make good hydraulic lime.

Although hydraulic lime even when finely ground is much inferior in strength to Portland cement, as Mr Grant's experiments proved, it possesses an advantage insomuch as its strength is greatest when mixed with twice or thrice its own bulk of sand; on the other hand, both Roman and Portland cements diminish rapidly in strength in proportion to the relative amount of sand or aggregate which is added thereto. So it sometimes occurs that lime concrete under certain conditions costs less than cement concrete, measured by strength. This is, however, an exceptional occurrence. Mr Bernays, civil engineer for the Chatham

Dockyard extension works in 1866, found that one of lime to six of ballast was inferior in strength to one of Portland cement to twelve of ballast, the cost at that time being identical.

Lime was used by the Romans for all their constructional works both for mortar and concrete, and the buildings and remains of buildings erected by them afford sufficient evidence of how well they understood its nature. It was used by them as a matrice, or more correctly as a grout for making concrete, but in Rome they mixed therewith puzzolana, a sandy element of volcanic origin, the best being found in the vicinity of Rome.

In the absence of puzzolana in this country the Romans and Normans used pounded shells, tiles, bricks and burnt clay, which proved good substitutes, as we know by walls still in existence; both Normans and Romans were aware that when hydraulic lime was not available, pounded bricks and tiles converted a non-hydraulic lime into an hydraulic mortar and grout.

Puzzolana is almost unknown in this country by the majority of people at the present time, although it was in use up to about 1870 and was specified in Government contracts no longer ago than 1867, forty-three years after the invention of Portland cement. Mr Bernays, C.E., said, in a paper read before the Institute of Civil Engineers in 1880, that in 1867 the first contract for the extension works at Chatham Dockyard specified that grey stone and blue lias limes were to be used for all ordinary mortar and for concrete, and puzzolana and Roman cement for mortar below high-water mark.

Mr John Hawkshaw, a well-known engineer, said that the Romans appear to have always used puzzolana in their mortar for aqueducts and more important buildings, but that non-hydraulic lime was employed, and that in his experience puzzolana should not be used with hydraulic lime; on the other hand, Smeaton used Watchet blue lias lime mixed with puzzolana for building Eddystone lighthouse.

Lime to be used as a matrice should be ground, not water slaked and sieved, as practised in some parts, and instead of using it fresh from the kiln, as was at one time specified, my experience is that it should be kept in a dry weather-tight shed having a wood floor, for at least a month before it is wanted. Where it could be well aerated I found it then made not only good concrete for foundations, but also for monolithic walls 12 inches in thickness and less, above ground, and which remain perfectly free from any signs of weakness or expansion and contraction.

There are conflicting opinions as to whether lime should be used fresh or allowed to season. General Treussant, a French engineer, said that hydraulic lime should be taken fresh from the kiln and ground and used at once, whereas Smeaton had it ground and packed in casks ready for use when wanted, for building Eddystone lighthouse, and employed Aberthaw lime elsewhere seven years after it had been ground.

If sieved through a fine sieve there will be found in most hydraulic limes a quantity, more or less, of somewhat coarse particles of an uncertain character. These are sometimes taken to be unground particles of lime, but they are not necessarily so, as the limestone often contains granular sandy substances which will not calcine, and a portion of the silica which forms a component part of the limestone is granular. Hydraulic lime and Portland cement possess considerable affinity; one part of cement, two of lime, and twenty-one of a suitable aggregate form excellent concrete. I have erected monolithic walls with these proportions which were quite satisfactory, although I am aware this union of the two materials is not generally advocated.

Roman cement took the place of lime to some extent as a matrice for concrete, until it was ousted by Portland cement. It was invented by Mr Parker, and originally called "Parker's cement." The patents of protection are dated respectively 1791 and 1796, the latter for improvements in its manufacture. The term "Roman" was given

it by Mr Parker, ostensibly because he believed it was a similar material to that which the Romans employed for their more important works.

During Sir Robert Peel's premiership it was held in such high estimation that Parliament proposed to tax foreigners dredging for the stone from which it was made. Mr James Wyatt was one of the first to introduce it to public notice, and it was then sold at the extraordinary price of 5s. 6d. a bushel, which enabled Mr Parker to realise a large fortune from its sale.

Parker's, or Roman cement was made from stone found on the beach at Sheppey, but Mr Frost, having discovered that it could be made from similar stone at Harwich, established a factory for its manufacture, and both Parker's and Frost's cement were extensively used for many years. But the strength of both was found to be very much weakened by the addition of sand, and for many purposes it was therefore used neat.

It set too quickly to be used as a matrice in concrete, and the latter had to be mixed in small quantities and used quickly. It absorbed moisture very rapidly, which necessitated it being used fresh, or it lost much of its strength, so that as a matrice it was of little value.

Medina cement, made in the Isle of Wight, is a variation of Roman, the only difference being that there is more lime in its composition, but in a general way it possesses both the advantages and disadvantages of Roman cement.

Selenitic cement appeared likely at one time to find favour as a matrice for concrete, but measured by strength it would not compare with Portland cement, as the experiments by Mr Grant proved. The reason why it was called cement when it consists wholly of lime is, according to General Scott, that the name "cement" belongs to any cementitious material which unites with water and passes into the hydrate in one operation, whereas lime slakes first and combines with silicic acid after. Selenitic lime is ordinary lime—hydraulic or non-hydraulic—to which a

small proportion of sulphate of lime, 5 to 10 per cent., such as plaster of Paris, is added. The effect of the added sulphate of lime is to increase the strength, render it quick setting, and prevent expansion.

The name "selenitic" is derived from the word "selenite," the chemical term for gypsum, the stone from which plaster of Paris is made.

Selenitic lime was invented by General Scott, an engineer officer, in 1870. In a lecture to the Architectural Association in 1871 he stated how the idea occurred to him of adding sulphate of lime to carbonate of lime to prevent slaking when water was added. He said: "While making some experiments with the Plymouth limes, in the course of which I found an excellent hydraulic lime among some beds generally rejected for burning, I discovered certain curious effects produced by burning the stone in a dull fire; I found in fact that the lime burned in this way, in lieu of slaking and heating as I anticipated, when reduced mechanically to a fine powder and treated with water, set into a solid mass. After many experiments I ascertained that this action was really due to the presence of a small quantity of sulphate of lime, resulting from the oxidation of sulphurous acid arising from the fuel which had been mixed in along with the lime in burning."

Previous to this, however, General Scott had found a way to obtain the same effect by placing vessels containing sulphur beneath limestone in a lime kiln during calcination, and in this way impregnating the lime with sulphur fumes. It was, however, too costly a process to become commercially successful.

The strength of selenitic lime as a matrice for concrete is so small in proportion to Portland cement, that for concrete purposes it is comparatively little used. Mr Grant said he found the tensile strength so small that test blocks sometimes did not bear winding up in the machine. In my own experience it was quite a failure for concrete purposes, but this may have been owing to the original character of the lime.

Plaster of Paris, or sulphate of lime, is made by burning gypsum from the Derbyshire, Sussex, and other quarries, and as a matrice for concrete floors was much used previous to the introduction of Portland cement.

It has, however, numerous disadvantages when compared with the latter. It sets too quick for concrete made in the usual way; it expands considerably when water is added; it is non-hydraulic; has much less strength than Portland cement, and oxidises iron and steel to a great extent wherever it comes in contact with either, more especially steel. The extent of oxidation may be judged from the fact that the hard-stone variety contains 58 per cent. of sulphuric acid and the softer 48 per cent.

Lime, when mixed with plaster of Paris, neutralises oxidation to a great extent, or if sufficient is added, almost entirely so. We see this in the use of gauged lime mortar for plastering purposes. When, however, plaster of Paris was used as a matrice for concrete, and iron beams and joists were employed to support the latter, the action was more apparent, as a much larger amount was used, and no lime or but a small proportion was mixed with it. Where alterations have been made to existing buildings erected forty to fifty years since, and in which concrete floors with plaster of Paris was the matrice, oxidation of the iron beams is often very much in evidence, in some instances seriously jeopardising the stability of the floors.

Great care is necessary in dealing with old concrete floors, where plaster of Paris was the matrice.

Within my own knowledge, I know of an instance where the old concrete made forty years since was broken up, and re-used with Portland cement as a matrice, the result of which was, the concrete expanded and a failure was the result. It was necessary to raise an old floor of plaster concrete, and of the same age, 2 inches. This was done with Portland cement concrete, which, after the lapse of some time, heaved up in various places, and examination showed that it was the old plaster concrete that had swollen

through contact with the water in the cement concrete. A layer of asphalt was used on a similar floor, and the 2 inches of cement concrete laid on as before. No movement took place. Willesden paper was tried as a substitute for asphalt, but the water percolated through the laps of the paper and caused a failure. This goes to prove that expansion of plaster of Paris used as a matrice in concrete, takes place, when water is applied, for many years after. In my own experience, an iron tie-bolt passed through a concrete floor of this description, and for 2 inches beyond contact with the concrete and where no dampness seemed possible there was considerable oxidation and wasting, gradually diminishing as the distance increased. There was no apparent cause for this; the result seemed a puzzle.

The inventor of Portland cement never for a moment probably contemplated the revolution it would make in building and engineering works all the world over. He described himself as a bricklayer, and it would be interesting to learn by what means he acquired the knowledge that led up to so important a discovery. Like most other inventions the original process of manufacture was of a primitive character, but it has now become one of a distinctive scientific nature, with the result that there is a very wide difference in the Portland cement of to-day and the Portland cement of Aspdin's time.

Although Aspdin, in his specification, calls his invention "Portland cement," he alludes to it in his title as "An improvement in the mode of producing an artificial stone." The date of the patent is 21st October 1824, and a portion of it reads as follows: "My method of making a cement or artificial stone for stuccoing buildings, waterworks, cisterns, or any other purpose to which it may be applicable (and which I call Portland cement), is as follows: I take a specific quantity of limestone, such as that generally used for making or repairing roads, and I take it from the roads after it is reduced to a puddle or powder, or the limestone, as the case may be, is calcined. I then take a specific

quantity of argillaceous earth or clay, and mix it with water to a state approaching impalpability, either by manual labour or machinery. After this proceeding I put the mixture into a slip pan for evaporation, either by the heat of the sun or by submitting it to the action of fire or steam conveyed in flues or pipes under or near the pan until the water is entirely evaporated. Then I break the said mixture into suitable lumps, and calcine them in a furnace similar to a lime kiln until the carbonic acid is entirely expelled. The mixture so calcined is to be ground, beat, or rolled to a fine powder, and is then in a fit state for making cement or artificial stone. This powder is to be mixed with a sufficient quantity of water to bring it to the consistency of mortar, and thus applied to the purpose wanted."

Aspdin's son in partnership with others established a cement manufactory under the name of Maud, Jones, & Aspdin, at Northfleet, near Gravesend, about 1828. Subsequently the firm became known as Robins, Aspdin & Co., and later as Robins & Co.

In a book entitled the "Bricklayers' and Plasterers' Guide," published in London in 1829, five years after its introduction, it is not mentioned; and in the earlier volumes of the *Builder*, published twenty years subsequent, it is scarcely noticed. Mr James Wylson, the founder of the Architectural Association, writing in the *Builder*, in the year 1844 (twenty years after Aspdin's invention) on limes and cement, names Portland cement as a cement just introduced into London, and in the following year Mr James Pulham in a communication to the *Builder* says: "Maude's Portland cement has not been in use a sufficient time to test its merits, but appears to stand well for stucco and mouldings, and is of a superior colour to Roman cement." In Redgrave's "Calcareous Cements," 2nd edition, published in 1905, it is stated: "Portland cement from Wakefield was used in the Thames Tunnel about 1828, although at that time it cost 20s. to 22s. per cask, beside

the carriage to London. Yet Sir I. Brunel decided, notwithstanding his ability to procure Roman at 12s. per cask delivered on the spot, to adopt Portland chiefly for his purpose, as its merits required no other recommendation than an impartial trial." From this we may assume that the Thames Tunnel was the first engineering work of importance in which Portland cement was used, for no doubt in its early days it was mainly a stucco cement, and it was not until very much later that it acquired the confidence of the engineering profession.

Evidently it did not occur to Aspdin that its value was more in the direction of an hydraulic mortar than as a stucco, for he only claims in his patent "An improvement in the mode of producing an artificial stone." Frost established the first manufactory on the Thames at Swanscombe; this was in 1825, but probably it was intended for making Roman cement, as Aspdin would scarcely have granted patent rights to another manufacturer so near his own proposed works; later, on the expiration of Aspdin's patent, he took up the manufacture of Portland, instead of Roman cement. Frost failed, and Messrs J. B. White & Sons purchased the business and works in 1845, and soon made the former a success.

As showing the slow progress the use of Portland cement made, Aspdin's patent was dated 1824; Frost erected a factory—possibly for manufacturing Roman cement in the first place—in 1825; General Pasley was commissioned by the Government to make experiments with limes and cements in 1826 which he continued for years. Messrs J. B. White & Sons commenced making Portland cement in 1845. General Pasley, writing to Dr Garthe, of Cologne, in 1852, said that although living within ten miles of Robins & Aspdin's factory he had never heard of what they were doing, nor of the inventor's factory at Wakefield, until he met Mr Aspdin at the great Exhibition in 1851.

General Pasley says in his treatise on "Limes and

Cements," dated 1847: "There are at present three manufactories of artificial cement in England, which have all been used more or less extensively in works of importance, and have given satisfaction, viz., that of Messrs J. B. White & Sons, at Swanscombe in Kent, the present proprietors of the late Mr Frost's works; secondly, that of Messrs Evans & Nicholson of Manchester; and thirdly, that of Mr Greaves of Stratford-on-Avon."

General Pasley's experiments were carried on at Chatham, where the best materials for the purpose were available, namely, chalk and the alluvial clay of the Medway, but he appears to have based his researches for years on the result of Smeaton's experiments and his statement that with the clay obtained from the lias limestone he made a brick, and so instead of using the alluvial clay, which was close at hand, General Pasley practised with the brown pit clay from which the grey stock Kentish bricks are made, and with no great measure of success. In 1828, he writes in his book on "Limes and Cements": "I gave an assistant instructions to mix two parts of chalk to one part of clay without stating the kind of clay, and as the Medway clay was more readily available, the assistant unwittingly used that instead of the brown pit clay, and the result was an unexpected success."

The proportion of raw materials he used was almost identical with that which makes the best cement at the present time, viz., 66 per cent. of carbonate of lime and the constituents of the clay making up the remainder. So that General Pasley lost the honour of having invented Portland cement by an interval of about four years. Probably, however, he knew of Aspdin's patent, which specified the use of argillaceous earth or clay.

The original Portland cement was a weak product compared with Portland cement of the present day. Chemistry had little or nothing to do with its manufacture; the standard guide was the convenient "rule of thumb," and the result as would be expected.

The materials of which Portland cement are manufactured—chalk and clay—vary in their components in a natural way, so that it is not possible to fix upon a certain amount of each and assume that the correct proportions may be obtained in this manner. A staff of analytical chemists is unavoidable where the highest grade of cement is the object, and this alone renders its successful manufacture on a small scale—unlike lime burning—impracticable. General Pasley discovered this, although his materials were all derived from the same source; unfortunately he was not a chemist.

Mr A. C. Davis, F.C.S., says that the normal condition of good Portland cement is within the following limits:—

	Per cent.
Lime	60 to 65
Silica	20 „ 24
Alumina	6 „ 8
Oxide of iron	2 „ 4
Magnesia	1 „ 3
Sulphuric acid	5 „ 2

The German Association of Cement Manufacturers gives, as the average analysis of the best German cements, the following result:—

	Per cent.
Lime	63.15
Silica	22.38
Alumina	7.83
Oxide of iron	2.51
Magnesia	1.79
Sulphuric acid	1.75
Silica ÷ alumina	2.95
Silica ÷ alumina + iron	2.02

Mr Henry Reid, in his work on "Concrete," published in 1879, gives the average result of six of the samples from makers of good reputation as follows:—

	Per cent.
Lime	60.82
Silica	22.48
Alumina	9.10
Oxide of iron	2.88
Magnesia	1.04
Sulphuric acid	0.37
Sand	0.42
Potash	0.62
Soda	0.42
Sulphate of lime	0.87
Carbonic acid	0.37

From this we may gather that the constituents of good cement thirty years ago differed little in their proportion to the best cements of the present time. Of these constituents, chemists tell us that sulphate of lime, while of no practical benefit, helps to hasten the set of cement; alkalies, potash, soda, &c., are harmless, but carbonic acid is very injurious, and magnesia is simply an impurity in the chalk, and if it exists to a greater extent than 2 to 4 per cent. may cause expansion and disintegration.

Mr Reid gives the following analysis of cement used for making concrete for the erection of certain walls which collapsed:—

	Per cent.
Lime	34.56
Silica	20.63
Alumina and oxide	11.26
Magnesia	1.44
Carbonic acid	11.19
Coke	3.21
Alkalies	1.93
Water	15.05

With regard to the effect of magnesia in cement, Mr George E. Walsh, an American expert, says: "Carbonate of magnesia is one of the common impurities found in clays otherwise suitable for making Portland cement. Nearly all Governments limit the presence of this impurity to 4

per cent. in the finished cement. Anything above this amount weakens the value of the cement by causing undue expansion. The peculiar action of carbonate of magnesia in cement by causing expansion may not be actually understood, but tests have shown that undue expansion has taken place when only 5 per cent. of magnesia was present. Sometimes this expansion occurs within a few days after the cement has been mixed, or it may not develop for a considerable time. Carbonate of magnesia has no hydraulic qualities, it is injurious to cement, and when above 4 per cent. it is a great injury thereto."

It was assumed and recognised at one time that Portland cement could only be manufactured from chalk and alluvial clay or mud deposited by the Thames and Medway, but at the present moment there is possibly no country in the world where it is not being made or cannot be produced, although of very unequal quality. It may be that in course of time a natural product may be found that combines all the elements necessary for making good cement similar to the process of lime burning, in which case the manufacture would be simplified and the cost reduced, but the possibility at the present time is remote.

Mr Butler states that the soft marls of Cambridgeshire are capable of yielding a good Portland cement in this way. Mr Davis, of the Saxon Portland Cement Co., says: "Analysis of the Cambridgeshire marls proves them to be fluctuating in character, and although eminently suitable for making a first-class cement, the closest observation and most careful calculations of proportion are necessary, these having to be adjusted."

There are two different processes in making cement, one called the wet and the other the dry. By the former system the chalk and clay are reduced to fineness by the addition of water in wash mills consisting of circular brick tanks about 15 feet to 20 feet in diameter and 5 feet deep or thereabout. Series of revolving harrows break up the mixture, reducing it to a state of pulp, which is made to

flow through a tube or pipe to the grinding mill. Thence the material passes to the drying chamber, and is finally pressed into blocks ready for placing in the kilns and subsequent grinding into powder. But the process varies somewhat in accordance with the views of different manufacturers. In the other system the materials are mixed dry, and just sufficient water added thereto to allow them to be pressed into blocks for burning.

The kilns are of various classes, the dome or bottle, the Hoffman running kiln, and others, but the invention of the cylindrical rotary kiln, patented in 1869, marks a great improvement in the calcining process. Invented in this country, it was proclaimed a failure, was improved in America, brought back again as an American invention, and is now in use by the best manufacturers. It is usually 60 feet to 70 feet in length, and 6 feet to 7 feet in diameter. The method of working is described by Mr Davis as follows: "The kiln is lined with fire-brick, and mounted on rollers, and slowly rotated by gearing; finely ground soft coal is now used for fuel, and this is introduced into the kiln through a blower or fan by a jet of air issuing under a pressure of 60 pounds per square inch, taking its hot air from a clinker cooling drum. The cement making material is fed in continuously through a pipe at the upper end of the cylinder in the form of either liquid mud or dry powder, according to the process adopted for mixing. Descending gradually and meeting with the heat generated by the perfect combustion of the finely ground coal fed into the cylinder from the opposite end, it parts with any water that may be present, becomes heated to redness as it approaches the centre of the cylinder, loses its carbonic acid, forms little rounded balls which reach nearly white heat in the lower third of the kiln, and finally issues at the lower end as well-burned clinker in grains about the size of a pea."

As most people know, there have been immense improvements in the manufacture of cement within the last forty

years, and—as a result—in the quality and strength also. This is undoubtedly owing in a great measure to the many experiments made by Mr Grant, engineer to the Metropolitan Board of Works, 1858-71.

One of the main features in a good cement is its fineness, and it is generally acknowledged that the finer it is ground the greater its ultimate strength, all else being equal. Mr Grant stated more than thirty years since, that he had received some German cement which left 25 per cent. residue on 32,000 meshes to the inch sieve, a result never attempted at that time by any British manufacturer.

Major-General Scott said at a meeting of the Institution of Civil Engineers at the same period, that if no residue was left on a 1,600-mesh sieve it was fine enough for all ordinary purposes.

In 1870-80 the 50,000 tons of cement used at the Chatham Dockyard Extension gave a residue of 25 per cent. on 2,500 meshes to the inch. Messrs White Bros. said at the same time that 10 per cent. on a 2,500-mesh sieve was a good cement, and this formula held good for many years, was generally adopted, and was specified for the Forth Bridge piers and abutments, and other huge works.

Mr A. C. Davis, F.C.S., gives the following table as to the fineness of cement supplied, or could be supplied, by the best manufacturers at the present time:—

Sieve	50 × 50 - - - -	Residue nil.
„	76 × 76 - - - -	„ 2 °/₀
„	100 × 100 - - - -	„ 5 °/₀
„	180 × 100 - - - -	„ 14 °/₀

The 76 × 76 = 5,776 meshes to the inch is the usual fineness specified at the present time, with a residue of 2 to 10 per cent.

Canadian engineers specify 10 per cent. residue on 10,000 meshes to the inch; the War Office 2 per cent. on 2,500 and 10 per cent. on 5,776; the India Office and the London County Council 10 per cent. on 5,776.

The finer the cement the less it weighs, so that the old rule that the heavy cements were the best has had to be discarded, for if a heavy cement is specified it must be coarsely ground. Mr Grant tested this by weighing the cement under three different conditions. The first, as received by the manufacturers, weighed 116 lbs. per bushel. The same cement, passed through a sieve of 1,296 meshes to the inch, which rejected 20 per cent., weighed 102 lbs. per bushel. The same cement, passed through a sieve of 2,500 meshes to the inch, which left a residue of 30 per cent., weighed 99 lbs. per bushel.

Necessarily the fineness or otherwise of the mesh depends a good deal upon the thickness of the wire. The British Standard specification is that for a 5,776 mesh the diameter shall be .0044 inch, and for 32,400 mesh .002 inch. The wire is required to be woven, not twilled, and the cloth to be carefully mounted on the frames without distortion.

Another feature in connection with cement is that it loses weight by keeping. This is a paradox, for we should naturally assume that so absorbent a material would attract the dampness of the atmosphere and gradually become heavier, but Mr W. Parkes, an engineer, in the course of a discussion which followed Mr Grant's paper read before the Institution of Civil Engineers in 1871, said that the result of experiments he had been making proved that after it had been received from the manufactory three days it had lost 2¾ lbs. weight per bushel in some cases, and 7 lbs. in others—presumably after a longer interval of time.

Mr Faija made an experiment with the same object in view, and with the following result:—

EXPERIMENT NO. II.

When received 1 bushel weighed	- - -	113 lbs.
„ 1 month old „ „	- - -	110 „
„ 3 „ „ „	- - -	102 „
„ 6 „ „ „	- - -	100 „
„ 9 „ „ „	- - -	97 „
„ 12 „ „ „	- - -	95 „

Where it is required to test the manufacturer's weight cement should therefore be weighed as soon as received, otherwise it will be less than is charged for. Where agents and merchants stock cement and sell it by weight, and it is weighed when delivered, there must be a loss entailed on the seller. But the probability is that in nearly every case, although the purchaser buys by weight, he takes the latter on trust, and although he possibly gets the measure he does not get the weight.

The specification of the Metropolitan Board of Works in 1859 required the tensile strength of neat cement to be 180 lbs. per inch at seven days; previous to that time 160 lbs. was considered a fair test. Mr Grant's experiments were the primary means of rapidly increasing the standard or strength.

The British Standard specification for cement at the present time is 400 lbs. per inch neat at seven days, and 500 lbs. at twenty-eight days, and when gauged with Leighton Buzzard sand—one of cement to three of sand—120 lbs. at seven days and 225 lbs. at twenty-eight days, and the best manufacturers guarantee this, while the actual strength is often 600 lbs. neat at seven days.

The seven days' test is, however, not altogether satisfactory; the missing link is a knowledge as to what proportion the strength increases with age, and what its ultimate strength will be. Cement which gives a satisfactory strength at seven days does not always increase in strength at the same rate as a less satisfactory one, and, moreover the strength is only one element in its character, and as users are seldom chemists or cement experts, it is, as a rule, taken mainly on trust. At the same time a good seven days' test is an important piece of evidence in its favour.

Mr H. K. G. Bamber, of the Associated Portland Cement Manufacturers Ltd., says a good rough and ready test is, immediately on receipt of the cement on the work, to test it for fineness; sieves for the purpose are sup-

plied by various manufacturers; then to test the cement for setting time, ascertaining that it sets neither too slow nor too quick; then to make up pats of the cement of a mushroom shape and keep them in water for twenty-four hours; next place them in a saucepan or other utensil containing cold water and heat the latter gradually until it attains a temperature of 180 degrees Fahr., or thereabout, maintaining this temperature for three or four hours; if at the end of that time the cement is sound the quality may be relied upon as satisfactory.

There is, however, one certain way of securing cement properly seasoned, and that is to keep it for use as long as possible. If this is not practicable, good makers will supply it if requested to do so, and some will give the chemist's guarantee that the batch from which the consignment has been taken has been tested and found to withstand a certain tensile stress, and has been also tested for soundness and fineness as well. Users can then rest fairly safe as to the results.

Mr Grant made interesting experiments with a view of ascertaining which was the best way of mixing cement, by hand or with a mortar mill, with the result that at three months old the hand-made mortar was double the strength of that made by a mill, and at twelve months three times the strength. The result is curious and inexplicable, but is evidence that the manipulation of cement has a good deal to do with after effects. The mixing of cement is usually a happy-go-lucky process, and the difference in its ultimate value would astonish many people.

Mr Colson, an engineer of great experience, said at a meeting of the Society of Engineers: "It has been the habit to value Portland cement concrete from the point of view that no skilled labour was needed in its preparation; that it was a material of so simple a character that any man who could use a shovel could mix it; was this correct? He believed that the more skill and thought exercised in the manipulation of concrete the more satisfactory would

be the résult. The mixing was often left to the care of men who had no feeling of interest in the matter, and therefore cared but little whether the mass was properly mixed or not."

It scarcely need be said how important it is that clean water should be used with cement; the latter is a material very susceptible to injury by the use of dirty water and dirty aggregates.

Salt water appears to favourably influence the strength of cement. Mr W. Dyce Cay, engineer to the Aberdeen Harbour Works, gives the following result as the average of sixteen tests of 2¼ inches area, made about twenty-five years ago:—

EXPERIMENT No. 12.

Tensile Strain.	Fresh Water.	Salt Water.
7 days' test - - - -	836 lbs.	907 lbs.
14 " " - - - -	994 "	1,044 "
28 " " - - - -	1,088 "	1,179 "

Salt water is of course not often used—only indeed where it is more readily obtainable than fresh water—but the R.I.B.A. Committee on Reinforced Concrete gives no reason why salt water should not be used, although it decides against it.

Cement is usually sold by the ton of ten or eleven sacks, each as a rule containing two bushels, according as it may be of a light or heavy grade, but usually eleven, and the weight is stated to be, say, 200 lbs. or more per sack, but as cement is compressed a good deal in carriage and repeated handling, it will measure considerably less after being emptied from the sacks than when the latter were filled.

If the cement is emptied into a bin, or on a wood floor, it has to be measured in a box for use, and there is a

palpable loss. If the cement is guaranteed to have been tested and seasoned before leaving the manufactory, and each sack to contain, at that time, say, two bushels, and there is no convenience for emptying it out of the sacks, that ought to be sufficient if from a reputable firm.

Manufacturers usually fill the sacks by weight, and permission would always be given for purchasers to see for themselves at any time the general practice of weighing the cement and filling the sacks.

If the cement is emptied on a floor and a measure is filled by means of a sloping board with a rim on each side, kept just sufficiently sloping to allow it to trickle gently into the measure, the bulk will be considerably increased; this is the only fair way of testing what sacks of cement contain on delivery, or loose cement measures after it has been shot out of the sacks for some time.

So what with loss of bulk by cartage and compression, and loss of weight by keeping it to season, a contractor need exercise care where it is specified that the cement shall be measured in a box when used or by weight.

The R.I.B.A. Committee on Reinforced Concrete says that the cement ought to be measured by weight when used as a matrice for concrete. This would incur some trouble, as the weighing machine would have to be, or should be, where the concrete is being mixed, and where several gangs of mixers are employed each would require its own machine. I do not think that in a general way this system commends itself, for the reasons just given; moreover, anything that tends to increase trouble to workmen who are engaged in mixing concrete increases an inclination for shirking, and weighing cement is one of those things which would necessitate close and constant watchfulness on the part of the foreman or clerk of works; at times it would lead to delay, and if opportunity offered it would not get weighed.

Portland cement unfortunately is one of the few building materials that cannot be judged to any extent by the most skilled expert from a cursory examination. Colour and

weight were formerly held to be two features from which its character might approximately be estimated, but these are quite uncertain factors at the present time; fineness can be more readily ascertained, but this is insufficient evidence of quality; an inferior cement can be ground as fine as a good one. Unfortunately, too, a fair estimate of its strength and quality can only be arrived at when tested after an interval of at least seven days, and better still fourteen or twenty-one days.

In large towns where users of cement are unable, for want of storage room, to stock any quantity, and where it is often required miles distant from their works, there is a saving of cost in cartage and unloading and reloading in having it direct from the manufacturers, or from one or other of their depôts or agents, and as the available space in new buildings is usually too restricted to store any quantity to season, it is frequently the case that cement is used immediately after or within a very limited period of its delivery.

A great deal of cement is supplied by builders' merchants; they mostly keep stocks of different manufacturers to suit the demands of customers who prefer certain brands to others. When the merchant is short of a certain kind, cement of another maker is often filled in the sacks of the brand ordered. Obviously the more reputable merchants do not practise this deception, and possibly it is done more in the smaller provincial towns where the demand is less.

It would seem possible to have ties so made as to render it a difficult matter to tamper with the contents of the sacks without detection, as for instance ties with a coloured thread interwoven therewith, as is practised—for identification — with Government rope. Some manufacturers now seal the ties, but something more simple seems desirable. Builders' merchants' clerks and storekeepers are often credited with "ringing the changes" when a certain brand of cement is inquired for and is not

in stock, presumably in the interest of their employers, who possibly are unaware of what has been done. On one occasion, noticing a plasterer cementing the outside of a house, I inquired whose cement he was using, and he replied A.'s, but, he added, "I have had some delivered this morning in A.'s sacks which I feel sure is not A.'s cement." When the building was finished the tint of some portions was very different to others, to the plasterer's disgust.

Another difficulty with the use of cement which may lead to failure is that some manufacturers profess to make several qualities. This is an undesirable custom. Wherever cement is used, and for whatever object, it is for some purpose where lime mortar is assumed to be not good enough, and upon the use of which great reliance has to be placed; the object is clear to every one; cutting contracts necessitate cheap materials; some manufacturers state in their trade lists that they supply three qualities of cement —"first, second, and contractors'." The latter description is a libel on contractors who purchase the best.

Now that Portland cement is largely employed over all the country, and is usually received from the manufacturers, their agents, or builders' merchants in small quantities at a time, it is impossible for the user to test, or have tested, each consignment as delivered, even if so disposed. It would be interesting to learn how many cement testing machines and apparata are employed by the users of cement on buildings and for other purposes, or how many builders test or have their cement tested; the number of the latter would be out of all proportion to the number who do not.

In the larger class of buildings the clerk of works has ample duties to perform without testing cement, and it would seem to most people to be unnecessary to employ a man specially experienced in that direction, and so where it is supposed to be practised it is more often than otherwise a spasmodic operation.

Where large engineering operations are in progress it is a different matter: testing cement is usually an important factor in the carrying out of the works.

So that it becomes difficult in a general way to ascertain whether the cement we are using is up to standard requirements or otherwise, and when we realise the confidence that has to be placed in its quality, and the possible fatal results which may occur from its failure, it is a serious matter to have to deal with.

The only way to ensure comparative safe results is for manufacturers to test each batch of cement, say seven or fourteen days after it comes from the grinding mills, bag it up with some form of fastening that cannot be tampered with without detection, and send a copy of the test signed by the works' chemist with each consignment. Some firms are now practising this arrangement, and it would seem desirable that with a material so difficult to deal with, like some other articles of commerce, its description should be made compulsory; the best makers should raise no objection, but the contrary, for it would weed the market of much of the cement with which no guarantee is given or expected, the only recommendation being the price.

With perfected machinery for making cement, and the aid of skilled chemists, there should be no reason for making an inferior quality, assuming that the raw materials are of the proper description, except the saving in cost, which is out of all proportion to the difference in quality. Then there is the possibility of the inferior kinds being put into sacks branded as best, if branded at all. And where the same article is made in the same building, though of various qualities, and indistinguishable one from the other, the danger exists. That others beside the purchaser may not be aware of the quality, it is sometimes the custom to give fanciful names to the different kinds and which are branded on the sacks, such as "Cyclops cement," "Leviathan cement," &c.

If the sacks were simply branded 1, 2, and 3, denoting

first, second, and third qualities, the meaning would soon be clear to other people beside the seller and the purchaser. It is perhaps commercially impracticable to manufacture for sale only one quality cement. The usual article may be sound and reliable, capable of standing a high test and suitable for all ordinary purposes; but there are times and occasions when it is most important that, like Cæsar's wife, it should be entirely above suspicion, and where the price don't stand in the way. The best manufacturers can meet this requirement; it is simply a question of price. It does not take away the character of the usual quality even if described as the best. The "ferrocrete" of the Associated Portland Cement Manufacturers is a case in point where the greatest care is taken to obtain the best results, but at an extra charge to the consumer.

CHAPTER IV.

THE GENERAL APPLICATION OF CONCRETE.

THE aggregate having been selected and deposited in place, on boards by preference, and the proportion of matrice to aggregate decided, it may be thought that no further information is necessary, but that the materials simply require to be mixed with water and deposited in place where required.

This is not so; method is as necessary in the application of concrete as in most other matters. Whatever the concrete is to be used for—foundations, walls, floors, roofs, or any other purpose—equal care is necessary. When mixed by hand the desire on the part of many workmen is to perform the operation as unsystematically as circumstances permit. It is unattractive work — about equal to that of mortar making—and if a chance obtains, amalgamation of the materials is not what it should be.

It is interesting to observe the way in which concrete is often being made. It is by no means difficult to judge the occupation, in a general way, of the mixers; the bricklayer's labourer, more especially, if his practice has been confined to mortar making, chafes the concrete with the end of his shovel after the last turn over; he cannot resist the habit he has acquired in mortar making, the result of which is that if the aggregate is brick débris or furnace ashes or anything of a comparative soft nature, some portions get chopped asunder, and he has undone in a minor degree the entire coating of the aggregate with cement.

The navvy, on the other hand, after filling the barrow with concrete and before wheeling it away, pats it round the sides with the back of his shovel, as he would do sand, earth, or gravel, but for no purpose. Nor will either of this class of mixers, as a rule, give the materials the wrist twist so essential when the concrete is being mixed, but simply move it from one position to another, not turning it over, so necessary to ensure amalgamation of the materials.

The most efficient class of mixers are the best class of agricultural labourers; they have fewer prejudices and are willing to do what is told them; the town labourer, on the other hand, has his own view of the fitness of things, and acts accordingly.

In rural districts men live and work under healthier conditions, and as a result are in better form to take an interest in their occupation. My memory takes me back to many of this class, good, careful, steady plodders, who did their work better, and more of it, than average London labourers, who spurt when under observation and straighten their backs in the interval.

I would like to meet the former of bygone times, shake hands with them, and fight our battles o'er again. Many, alas, are—let us hope—reaping the reward of a life of toil.

It need not be said how desirable it is, for the sake of convenience and economy, that the aggregate should be deposited as near as possible to where it is likely to be required.

For country work this is generally practicable, but for town buildings exigencies of space don't often permit of a choice. In any case it should be kept at a distance from the lime shed, the mortar mill, and the place selected for running lime, as pieces of lime or lime core may possibly get mixed therewith and cause blows, or blisters in the concrete from expansion, after it has been deposited in place.

A platform or mixing board is absolutely necessary. It was the custom at one time to ledge the boards to form

two or three sections, or parts, to facilitate removal through doorways, &c., but it is preferable to use single boards laid together and kept in position, with a strip of wood—a slate batten for instance—nailed across each end, which prevents the materials passing over the sides. The size of the mixing board is one of convenience, but it should not be less than 10 feet square, and laid nearly level on a layer of sand if possible, and the boards of the same size as scaffold boards, *i.e.*, 9 by 1½ inches. The exception to the size of the platform is when the aggregate is to be washed, a practice seldom adopted at the present time, but a desirable one with most aggregates. In this case the mixing board should be 14 by 10 feet; this affords more space to wash and turn the materials over. Formerly I always washed the aggregate where water was plentiful and the conditions were suitable, but the necessity for so doing varies; river gravel requires more or less according to whether it is obtained from a sluggish stream or a quick one. Thames ballast requires none as a rule; ashes from furnaces and coke breeze a moderate amount, and old bricks and stone from buildings being demolished, and brickyard débris, usually more than any. The materials may not be dirty in themselves, in the sense of fitness for an aggregate, but all materials that have been crushed by a machine, broken by hand, or passed through fire are covered with a film of impalpable dust which is harmful to cement. The value of Portland cement is much lessened by coming in contact with deleterious substances, much more so than lime; dust is one of them, and fine sand or grit is another.

Although the necessity of a clean aggregate is admitted by every one, the objection to washing is that the finer portions get washed away if performed on a mixing board; this need not be if the latter is inclined sufficient only to allow the dirty water, the dusty element, or the almost impalpable grit or sand, and nothing more, to run away at the lower end.

The "washings," so called by workmen, if allowed to run

into a sump hole, form—if the aggregate is brick débris—a thick red pasty mass containing nothing that is necessary to retain in the aggregate, but much that is harmful. The extra cost of washing is but little, assuming water is available at a small cost, and there are means of getting rid of it. My practice was to deposit the aggregate, measured in the box, and the box removed, at the lower end of the mixing board, turn it back while water is being thrown over it with buckets, twice, which brings it to the upper end of the 12 or 14 feet board. Then wash away the dust and dirt remaining on the unoccupied portion of the board, and add the cement, turning the mass over twice back again in a semi-dry state, and twice while water is being added.

The shovellers will sometimes wait until their fellow-worker has poured several buckets of water upon the aggregate, and until a considerable portion has passed away; in that case the only result is to filter the water through the aggregate, leaving the dirt behind and performing no kind of service. The cleanliness of the effluent water will sometimes be put forward as evidence of the cleanliness of the aggregate, but if the latter is moved sharply there will be palpable evidence to the contrary.

But there may be no facilities for the water to disperse; inside a building in progress, more especially in a town, this is often the case, and as the washings would possibly choke any branch drain, washing the aggregate is not a common occurrence, but where it can be done the increased strength of the concrete, or the smaller amount of cement necessary to obtain equally good results, more than compensates for the increased cost of labour.

With regard to turning over or mixing the materials twice in a dry state and twice while water is being added, this has always been the custom advocated, I believe. Anyway good concrete made by hand cannot be safely produced otherwise. The system recommended by the R.I.B.A. Committee is as follows: "When the materials are mixed by hand they are to be turned over and thoroughly mixed

on a clean platform until the colour of the cement is uniformly distributed over the aggregate." The number of times the materials are to be turned over is not stated. Some aggregates if unwashed would so discolour the cement that nothing approaching its original colour would be apparent, crushed brick débris for instance or slag from iron ore. Moreover mixers might plead, and many would certainly practise the failing of colour blindness. The amount of aggregate washed at a time is immaterial, but it is more economical to wash it as it is being used. For this purpose the measuring box is necessary; that is, a box with four sides and no bottom, made with say three-quarter inch deal, and ledges nailed thereto at the four corners to

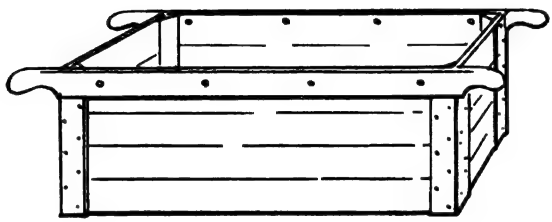


FIG. 1.

stiffen it. The handles bolted to the top are usually formed with 3 by $1\frac{1}{2}$ inch deal, and inside angle pieces about 2 by 2 inches (to make two) nailed to the corners.

A convenient size for the box is 4 ft. by 3 ft. by 1 ft. 2 in. in the clear, equal to 14 cubic feet, which is exactly two-thirds of a cubic yard, and if the proportion of matrice is one part to seven of the aggregate, the measure of cement would be 2 bushels. If the box is to hold a cubic yard, then 4 ft. by 3 ft. by $2\frac{1}{4}$ ft. in clear are suitable dimensions, and the proportionate amount of cement arrived at by dividing 21 (the number of bushels in a cube yard) by the given ratio. If one in seven then 3 bushels, one in eight $2\frac{5}{8}$ bushels, and so on, a box being used as a measure to hold the requisite amount, unless the sack of cement as received is taken as

containing 2 bushels, or whatever the proportion may be. The amount of concrete that should be mixed at a time depends on the purpose it is for; the object is to get it into place as quickly as possible, and before initial set commences; for foundations and similar work this can be accomplished in half the time, as a rule, that it takes for floors, walls, &c. Generally 2 bushels of cement for each mixing is usual for floors, and double that amount for foundations, but this is conditional.

The R.I.B.A. Committee says that concrete should be mixed in small batches. The question is what may be considered a small batch. Different practitioners have different views in this respect; a small batch for foundations would be a large one for floors. Obviously concrete sets more rapidly in hot weather than in cold, and in the sun than in the shade; the more absorbent and the drier the aggregate, the more rapidly initial set commences. A two-pronged hook or rake should also be provided for incorporating the ingredients. This should be similar to a plasterer's hair hook, but somewhat stronger, and with a handle 5 feet to 6 feet in length. An ordinary watering-pot to hold a pail of water is necessary, having a coarse "rose" attached, that the water may be distributed gently, not thrown on violently to wash the matrice from portions of the aggregate and undo what had just been done in the way of dry mixing.

The aggregate having been placed in the larger measure, the matrice deposited on the aggregate, the measure is removed by a workman at each corner lifting it perpendicularly by the handles, leaving the materials on the board in the form roughly of a cone or pyramid. Two men, one on each side of the heap, then begin to throw the materials to the opposite side of the mixing board; another, standing by the heap now forming, helps to mix the ingredients by raking them backward and forward with the hook until the heap has been reformed. The same process is then repeated, by which the materials are replaced where at first deposited.

Having now been turned over and raked "twice dry," the operation is again gone through in the same way, but with the help of a fourth man, who stands behind the heap and adds water from the watering-pot to such portion as the two men who are shovelling are immediately about to work upon. This makes three times turned and raked—once more finishes the process, and the concrete is then ready to be deposited where required after having been turned over and raked twice dry, once during the process of watering, and once after.

The following conditions should be observed :—

1. The water should be added to that portion of the materials the "shovellers" are working upon—not to the mass indiscriminately, as so doing would give the matrice time to sink through the interstices of the aggregate previous to attaining partial solidity.

2. Water should be added—as much as needed—during the third turning, not after, if possible.

3. The amount of water applied must be regulated according to the purpose for which the concrete is intended. For foundations, arches, &c., where impingement can be practised, only so much as to cause cohesion between the materials is necessary; but for walls between frames, and similar objects, it must be in a more semi-liquid condition.

4. The "shovellers" must turn the concrete completely over when in the act of casting it from one heap to form another—not merely removing it in their shovels without inverting the ingredients.

5. If the aggregate is porous, say Bathstone chippings or crushed bricks, it is better, especially in hot weather, to well water it and allow time for absorption previous to mixing, or the aggregate will have taken away a portion of the water required for hydration.*

6. Not less than four men should be employed for mixing,

* If a dry brick be washed with liquid cement and exposed to the sun's rays, the cement, when dry, will have become an impalpable powder, having no adhesive properties.

nor will the variable nature of the aggregate, or other circumstances, justify any departure from the method of making concrete as described.

No doubt it will be said: "Have you seen concrete made in this way outside your own practice?"—the reply to which is: I can't say that I have; but like most other things of a similar character it is a question of cost and if a fair price is paid to have the aggregate washed; but much has to be forgiven when the lowest offer for performing the work, often an unremunerative one, is accepted and known to be below prime cost.

Assuming concrete could be thoroughly mixed by a machine, there is no doubt but it would be better performed that way than in the perfunctory method common with hand labour.

Tests made by the United States Government as to the relative merits of hand-made and machine-made concrete gave the following result: at seven days old the hand mixed was 53 per cent. of the strength of machine mixed, at twenty-eight days 77 per cent., at six months 84 per cent., and at one year 88 per cent.; but it has not yet been found practical to adopt machines in place of manual labour for mixing concrete for ordinary purposes, so far as my knowledge goes. Turning the mass over as described takes considerable time, but on a level platform the labour is much reduced to what it would be on rough ground. No mixing machine that I know of can be worked by hand to advantage for ordinary building purposes, and an engine would be unprofitable except for foundations on an extensive scale where a considerable quantity of concrete could be got rid of, or similar purposes.

Concrete is too heavy a material to be violently agitated or mixed in a machine by hand power, unless in small quantities, or a cog-wheel arrangement to reduce the speed is adopted, both of which are objectionable, and if an engine and mixer is employed they would probably be idle a greater part of the time, except for engineering works

such as dock walls, bridge piers, abutments, and similar structures where large quantities are used and it is necessary to get the concrete in with expedition. Messenger's mixer was used for making concrete for the Tyne pier at Tynemouth, and cost about £120, and Ridley's mixer, with wheels and axles for travelling, about £100. Mr Stoney, the engineer of the Dublin harbour works, invented a useful mixing machine for concrete walls built under his supervision, and there are numerous American types.

The action of each is somewhat different; one violently agitates the materials simply through the mixer revolving on its own axis; another lifts a portion of the materials, then turns it over and allows it to drop, when it is immediately taken up again and the process repeated, while a third stirs the materials, passing them on to the mouth of the machine at the same time and in the same way that a hand mortar mill mixes and delivers mortar. For the Birkenhead docks a mixer invented by M. L. Mesurier was used. Mr R. E. Taylor, C.E., of Newcastle, is the inventor of a mixer which he claims can manipulate half a cubic yard at a time by hand power.

The Associated Portland Cement Company sell an American gravity mixer (Fig. 2), which consists of a steel trough filled with rows of steel pins and deflectors staggered in order to thoroughly mix the ingredients as they gravitate through the trough. An arrangement of valves and pipes enables the water to be introduced by means of spray pipes, about midway the length of the mixer. This is for the purpose of the materials being mixed dry in the upper half, and wet in the lower half of the machine. The construction is arranged so that the materials are scattered from side to side, and thoroughly incorporated before reaching the bottom.

A great advantage is that power is not required; when no mixing is being done it is at rest, costing nothing. These machines are made in various lengths; the illustration shows one 6 feet long with an attaching section;

but they are supplied with or without these additions in 6, 8, and 10 feet lengths. The agents are the Associated

FIG. 2.

Portland Cement Manufacturers, Limited, Dixon House, 72 Fenchurch Street, London, E.C.

The accompanying illustration (Fig. 3) shows a concrete mixer to work by hand, made by the Concrete Machinery Company, 18 Water Street, Liverpool.

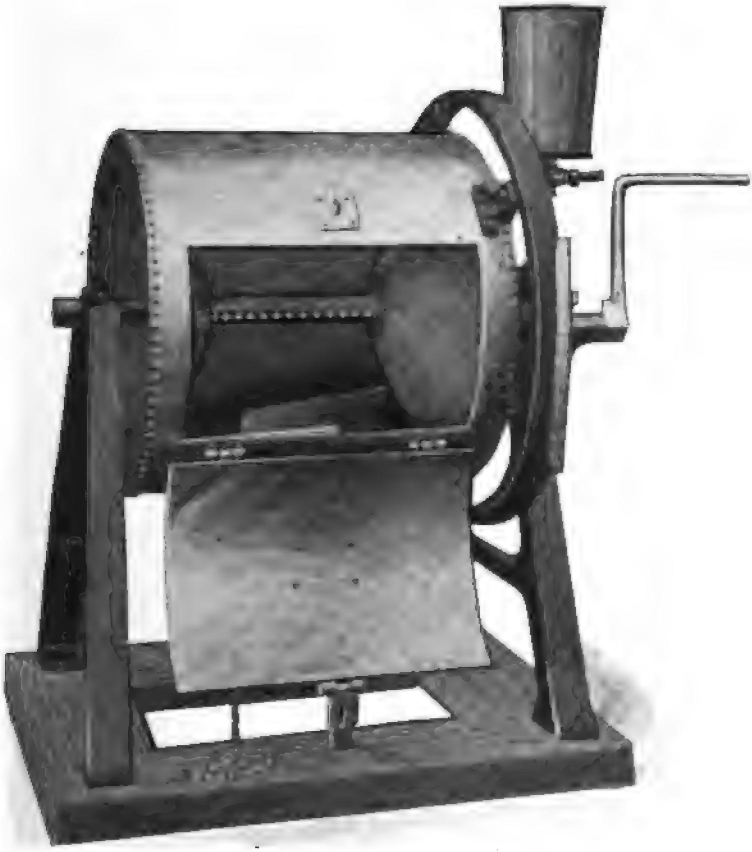


FIG. 3.

For carrying away the concrete from the mixing boards for foundations, wheel-barrows are of course best, but for walls, floors, and similar purposes galvanised iron buckets,

11 inches diameter at the top, are the most suitable, and with a flat bar round the top—not the iron rod usual in the cheapest kind. It is a mistake to use strong buckets, they are too heavy, and if a lighter kind is to be found any-

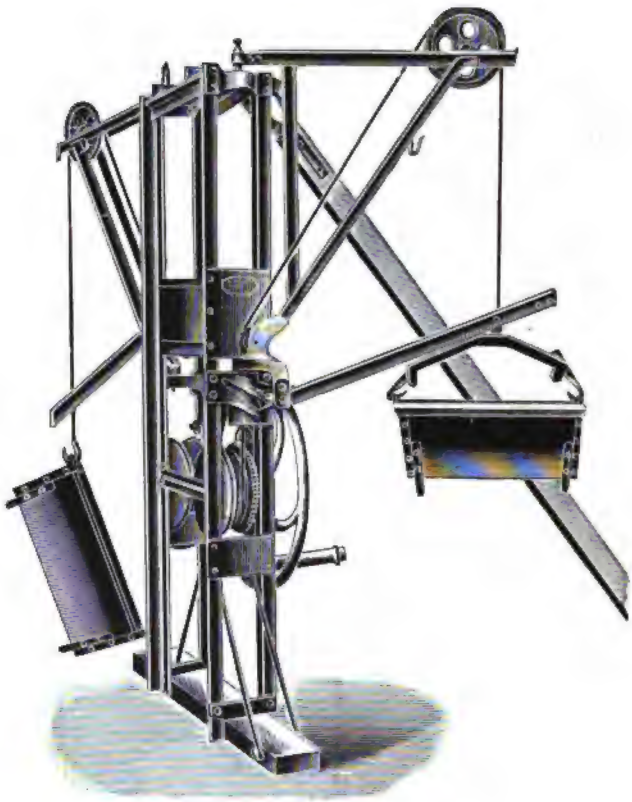


FIG. 4.

where on the building the larger ones are soon missing, and no one knows what has become of them except those who buried them. And it pays to have a lighter quality, even if two or three are worn out as against one heavier one.

For hoisting concrete an ordinary rubbish wheel and a

2-inch circumference Manilla rope is suitable for moderate heights. Manilla does not cause abrasion of workmen's hands that a hemp one is apt to do. Where the lift is considerable, but insufficient to employ an electric hoist, the best hand hoist in my experience is one supplied by Messrs Becker & Co., 53 City Road, London, E.C. (Fig. 4). It is portable, can be fixed anywhere, and is light. The special feature is a universal joint, consisting of a semi-spiral groove within which moves a ball formed at the end of a swinging guide bar, and controlling the movements of the guide, through the outer end of which runs a wire rope from which the load depends. The arms work in pairs and in contrary directions, one rising with the load as the other descends empty; the former swings round automatically and delivers the load into barrows, or on to a stage. This lift is a great time saver in hoisting concrete.

In moderately warm or mild weather cement sets quicker than in cold weather. This is partly owing to the temperature of the water employed for mixing. It is unwise to attempt to make concrete with the thermometer below freezing point. It is done at times under pressure of circumstances, and the concrete deposited in place before it is affected by freezing; but it is almost unnecessary to say how dangerous this is. Mr Newton, an engineer, suggests that concrete should not be made or employed when the temperature of the air on the ground is below 40 degrees or above 90 degrees, and that the temperature for water used for mixing concrete should not be less than 40 degrees. My own experience is that the best concrete for general building purposes is made when the temperature is near to but not below freezing point—32 degrees—provided it is fairly certain not to fall below that point until the concrete has set. In common practice but little regard can be paid to the temperature of the air or water; undoubtedly very hot weather is unsuitable for concrete work, especially if it is exposed to the sun.

It has been attempted, and indeed some builders' guide

books profess to give with accuracy the quantity of water needed for a specified amount of concrete; but this is impracticable; it cannot be stated approximately even. The aggregate is perhaps of an absorbent nature or the reverse; it may be quite dry or very wet; it may be composed of coarse, or on the other hand of comparatively fine materials. Each of these conditions affects the amount of water needed, and it is only by practice that the proper quantity can be ascertained.

There is much difference of opinion, especially among engineers, as to the best condition for concrete. Some advocate the use of abundant water, others but just enough to obtain cohesion. When the concrete can be tamped or compressed, undoubtedly a moderate amount only should be employed, but if neither is practicable, except to a very limited extent—as for walls and floors—a more sloppy or pulpy state is essential, otherwise the concrete cannot be rendered homogeneous by reason of its dryness and stickiness, and consequent inaptitude of its particles to fill every crevice and interstice of the mass.

Experiments made by the United States Government officials proved that "sloppy" concrete became much harder eventually than when only just water enough was added to create adhesion, but it took longer to acquire hardness. An advantage of well saturated concrete is that it does not require so much tamping or beating, and in some cases none at all.

When the aggregate is washed, previous to mixing, on a slightly sloping mixing board, and the concrete holds as much water as it can retain without carrying away when at rest any portion of the lime or cement, it is in a suitable state for ordinary walls, but would be too liquid for foundations.

As before stated, salt water causes cement to become stronger than rain or spring water, but for building purposes is unadvisable.

American engineers calculate that 10 per cent. of the

weight of water is the maximum amount of salt that should be in solution, and that the only effect it has on the concrete is to somewhat delay the hardening; but except to delay freezing when frost is imminent, salt water for concrete should not be used.

Rain water, from trials made, appears to suit cement slightly better than spring or river water. A choice seldom exists in building operations, but whatever kind is available it should be as free from foreign ingredients as possible to obtain it.

It is a peculiarity of Portland cement that it will not readily take up more water than is necessary for mixing, either with sand for mortar or with an aggregate for concrete, and if an excess is added the cement will part with it if opportunity offers. This is a curious property of cement; if it applies to lime it prevails in a much less degree; but there is no mistaking it in cement; if we could see the bottom of concrete after it had been trodden or rammed for foundations, we should find clear water, and on the top a sheet of writing paper could be saturated therewith and not soiled; in a short space of time the effluent water disperses itself in the minute cavities of the concrete. No positive harm arises from this effluent water that I know of, as its dispersal is gradual and gentle, and the cement having acquired an initial set is not disturbed thereby, but it points a lesson with regard to the use of water, viz., that although sufficient is needed an excess is unnecessary. Perhaps more care is essential in this respect when the artificial foundations rest on a bed of clay or other non-absorbent material. If an unreasonable amount of water is used, the effluent water, instead of dispersing or throwing itself off, is in sufficient force to take with it a portion of the cement, and a serious weakening of the material ensues. In the case of concrete foundations this depletion results in pure cement being carried to the bottom thereof, and in walls or floors wherever it may most readily find means of escape. If tricklings of cement are seen on

the supporting boards of floors, or the encasing panels of concrete walls, it is direct evidence that too much water has been employed.

The action of frost upon cement during the progress of setting is peculiar; the set seems to be entirely suspended when the temperature falls below 32 degrees Fahr., and when a thaw commences the cement apparently sets without injury; not that concrete of itself remains uninjured, for the water crystallises under the influence of low temperature, causing the cement to expand, and rupture more or less of the concrete may take place. Undoubtedly, if a certain stage of setting has been reached frost has no effect upon concrete. I have had concrete removed by hand, without trouble, days after it has been made, under the impression that it was irrevocably damaged, only to find the condemned fragments, much to my astonishment, eventually become as hard and sound as any part of the work. When therefore a frost occurs, and newly made concrete appears to be considerably injured, let it remain if possible for several days after a thaw has commenced, and if it be a monolithic wall then sound it gently with a hammer in the same way that plastering or stucco work is tapped to ascertain if adhesion is perfect. Mr P. M. Bruner, an engineer of St Louis, U.S.A., made some experiments in connection with the effects of frost upon cement, and gives the result as follows: "Ten test samples were made; five of these were left twenty-four hours in a room of which the temperature was 40 degrees Fahr.; they were then placed in water; the other five samples were immediately placed out of doors and exposed for forty-eight hours to a temperature of 10 to 6 degrees Fahr., and then brought to a room of which the temperature was 40 degrees Fahr.; they thawed out in a few hours, became almost as soft as when first made, and at the end of twenty-four hours had set; they were then placed in water with the former five tests; at the end of a couple of months all the ten tests had the same tensile strength."

The result of Mr Bruner's experience and observations is given as follows:—"Whatever will counteract or limit the expansion or control the freezing, will to that extent counteract, limit, or control the injurious effect of freezing on fresh concrete. By counteracting the expansion is meant any means of bringing the mass to its proper volume during the thawing out, or immediately afterward. By limiting expansion is meant a limitation of the quantity of water used in making concrete, or a provision for the draining off of any excess as rapidly as possible. Be it remembered that it is the water that freezes rather than the concrete as a mass. The expansion can therefore be limited by limiting the use of that which brings about the expansion. Any one failing to confirm the experiment with the ten test samples above mentioned, would probably find the cause of the failure in not noting this point. This point will also account for the fact that blocks of concrete made earlier in the day will escape injury by frost, while those made in the evening will be injured. Where the expansion cannot be sufficiently counteracted or limited, and where the concrete cannot be properly mixed on account of the cold weather, there still remains one method, that of controlling the freezing. We can lower the freezing point of the water by adding some neutral substance. The most available perhaps is common salt, and this lowers the freezing point of water about 1 degree Fahr. for each per cent. by weight added to the water. A series of experiments made for the purpose of indicating the propriety of its use, with regard to its effect on the cement, shows that up to the limit of the saturation of water no harm results from its use. This is in part accounted for by the fact that plasticity is obtained with less of the solution than with water alone."

With reference to painting steel work previous to delivery on the works, and which used to be a very strict condition, it is probable that it affords very little protection, and that the oxidation on the steel previous to

being encased in concrete—unless the delay is very protracted—is of little consequence. It has been stated that the action of cement on rusted steel is practically to destroy the rust. This I suggest is scarcely probable, but that the concrete, acting as a blister, removes the rust, which being diffused in the concrete is imperceptible. A Portland cement wash is probably better than paint, but if put on dry steel—more especially in hot weather—it is easily rubbed or washed off: to remedy this to some extent, if the steel surface is washed over with water, and left until it is damp only, it adheres very much better. A suitable fixing material to add to Portland cement, so far as I know, has not yet been discovered. I have tried various kinds; good results have been obtained by washing the steel with Portland cement of the consistency of cream, alum having been added to the water in the proportion of four ounces to three gallons of water, but the best proportion can be ascertained by experiment. It should be applied when the steel is quite damp.

CHAPTER V.

CONCRETE FOUNDATIONS.

ALTHOUGH equal care is necessary in the application of concrete, no matter its purpose, the methods of dealing with it vary. For foundations it is usually tipped in from barrows, and the aggregate is better for being of a coarser grade than is usually employed for floors and walls. At one time it was the invariable practice to specify that it should be tipped in from a considerable height, sometimes as much as 10 feet. It was thought that this ensured more solidity, which no doubt it did, but it was found that the larger pieces of the aggregate, having more velocity, sank or settled beneath the finer portions. The custom has therefore been almost abandoned, and the concrete tipped into the trenches from a lesser height. No doubt it is more solid if dropped from a few feet—four or five, and at this distance the coarser portions of the aggregate would scarcely acquire more momentum than the finer. The less cement concrete is disturbed after it is once deposited in place the better; initial set soon commences, and its disturbance by ramming or beating at one point helps to cause the surrounding portions to rise and their particles to be agitated.

The recommendation of the R.I.B.A. Committee that concrete should be deposited in layers not exceeding 3 inches in thickness will not, I think, find favour; it would take longer to perform in a general way, and still more so for foundations. Six inches in thickness between each punning or beating, if either are practised, for foundations is, I suggest, reasonable, but much depends on circum-

stances. The Concrete Steel Engineering Company, of New York, specify 6 to 8 inches.

Our ancestors frequently, when erecting massive structures, appear to have bestowed but little care on their foundations, which is somewhat remarkable. Walls have been found in many instances to be no thicker at bottom than at top, and bear upon the natural subsoil, although concrete has been known and applied from time immemorial.

The proportion of matrice to aggregate is a matter of opinion, the weight to be supported, and the nature of the soil. Five or six parts of blue lias ground lime to one of an aggregate, and ten parts of cement to one of an aggregate, should be good enough for almost any purpose.

Philibert de L'Orme, a noted French architect, writes in 1568: "Having thrown in a layer (of concrete) about half a foot in thickness, large single stones may also be thrown in and mixed here and there with it as it may be convenient, but without touching each other; after this throw in more (concrete) and repeat this process until the excavation is full."

It is a common practice in Italy and other parts of the Continent to first deposit a layer of concrete or *beton* a foot or less in thickness over the entire area of the bottom of all trenches, and on this are placed layers of broken stones, and the stones well worked into the concrete; then another layer of concrete and stones as before, and so on alternately concrete and stones to the full height required. Philibert de L'Orme tells us this was the practice long anterior to the time he wrote, about 1568. It was the method undoubtedly of all ancient nations who used concrete for foundations, and although not often adopted in this country, the effect would be a considerable saving in cost and an equally good result, provided the proportion of stone to concrete was not too great; where however so much of this kind of work is done by contract and at cutting prices, the temptation to reduce the most expensive material and

increase the amount of what concrete users call "packing," is, in foundations where everything is rapidly put out of sight, oftentimes too great to be resisted. The amount which may be employed depends on the solidity of the substratum and the character of the superstructure the artificial foundations have to support, but if used at all no two pieces of packing should be nearer together than 6 inches, or within 3 inches of the inner and outer face of the concrete, and no layer of concrete should be less than 6 inches in thickness. Where less than 1½ foot in depth of concrete is required the use of packing can scarcely be recommended.

Concrete for artificial foundations seems to have experienced cycles of use and disuse. Many of the curious ancient buildings in Mexico have substantial concrete foundations; the Romans at one period used it extensively, and at a later date apparently very sparsely, while in the last and previous century piling and planking was the favourite system adopted in this and other countries.

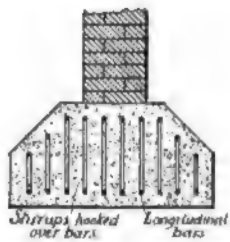


FIG. 5.

Footings were originally intended for the purpose of distributing the superincumbent weight of the walls and buildings over a greater superficial area. A cement concrete foundation renders footings for walls unnecessary; they give no assistance to the concrete, nor does the wall above the footings derive any material benefit therefrom, always assuming that the concrete is of sufficient thickness for the purpose, is unyielding, and otherwise adapted to the load to be supported. A suitable section would be somewhat as Fig. 5.

The practice of concreting the entire area of buildings, rendered compulsory in many places, mainly on sanitary grounds, is a desirable practice. Where it is intended by so doing to not only fulfil that object but to afford a

suitable foundation for buildings erected thereon, and called raft foundations, it has necessarily to be of considerable thickness, more especially where the natural soil is of an insecure or uncertain character. The foundation platform of this nature for St Thomas' Hospital in London is 10 feet thick, and was executed in 1871.

Mr Bernays, M.I.C.E., made his raft foundations for Chatham Dockyard extension works only about 5 feet wide, and in a lecture delivered at Chatham in 1879 he said: "I should like to draw your attention to how to support buildings of a moderate weight on bad foundations. On nearly the whole of the extension works the ground has been made up over the original marsh level for an average depth of about 8 feet. The borings proved the ground, for a very great depth below the old marsh level, to be very soft. It has been necessary to erect many buildings in the neighbourhood of the docks and basins, but in no case, except under the standards of the great workshops at the head of the docks, have I found it necessary to use piles, or to carry the foundations down to a good bottom. The buildings generally have been laid on a broad shallow layer of concrete, got in as near the surface of the ground as possible. In bad ground nothing is gained by depth of concrete, unless it is carried to a good foundation, as it adds weight to the buildings to be carried; deep concrete on a bad foundation is prejudicial rather than beneficial. I have found that on made ground a building, if not of too heavy a character, may be safely carried when concrete 5 feet wide and from 18 inches to 2 feet thick is placed under the footings of all walls. You will see many buildings that have been constructed without crack or settlement, thus floated as it were upon ground not much better than mud."

Raft foundations can, obviously, be increased in strength in the same way as floors and roofs, viz., by reinforcement, nor does there appear to be any reason why they should be treated in any other way, except where the superincumbent

weight at any special points is of a nature to increase the necessity for a greater amount of reinforcement. Old railway metals are sometimes used with this object, but are inferior in a general way to ordinary systems, except for special purposes. A suitable section for reinforcement is shown by Fig. 5.

The French occasionally form a rim, lip, or flange to the edges of their foundations, somewhat like an inverted dish, by excavating deeper on the outside edges of the foundation trenches. In soft peaty soils this has the merit of confining the materials, and if the ground is apt to slide or "spew," as it is sometimes called, it tends to check this until the concrete has consolidated. In soils not of the most reliable character some practitioners let the concrete foundations project considerably more on the outside than on the inside of walls, as shown by Fig. 6, as the outer portion of the latter has no assistance from cross wall foundations and the lateral support of inner cross walls, and it is thought the weight of the building is in this way more evenly distributed over the foundations.

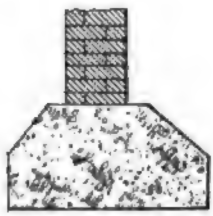


FIG. 6.

It may appear ridiculous to assert that in case of a large conflagration the stability of the walls depends a good deal upon the character of the foundations; but Captain Shaw, at one time chief of the London Fire Brigade, said: "In case of fire, walls may be destroyed by buckling outwards from a thrust, or inwards after the falling of the floors, by inherent weakness, absence of proper ties, and in a variety of other ways; but the principal cause of their 'tumbling about,' to use a fireman's expression, is undoubtedly in almost all cases the want of proper foundations. The weights carried by different parts of the same wall frequently vary considerably, and if the ground beneath be all of the same consistency, as is generally the case, some inter-

mediate structure beyond a common foundation is absolutely necessary for buildings liable to be heavily or irregularly loaded. The neglect of this precaution has frequently been the cause of heavy losses from fire. A careful inspection of many very heavily and irregularly loaded buildings, even after the shocks, thrusts, and other damages caused by serious fires, proves most satisfactorily that foundations of inverted arches, concrete, or any solid substructure, tend in all cases to reduce, and in almost all cases entirely to prevent fractures and settlements in the walls, and consequently, communication of smoke and flame."

Possibly no better plan can be adopted for consolidating concrete in foundations where tipping is not practicable, or levelling up to some extent is required, than to use a wood beater, made similar to a gardener's grass beater, by preference the face lined with a piece of zinc or sheet iron to diminish the concrete or lime adhering thereto. The beater should not be too large nor too heavy; if the former the concrete receives less impact, and if the latter the workman will apply less force in delivery; one about 12 by 9 or 9 by 9 inches and 2 to 3 inches thick is a convenient size, and should be made of elm or other hard wood not liable to split or crack.

If a smaller beater, or ordinary size rammer, is employed, the impact of the blows causes the surrounding portions to have a tendency to rise or lift, which a larger one prevents. Portland cement concrete, where special care is necessary for foundations, is unsurpassed for the purpose, it possesses the great advantage over lime concrete that while the latter cannot be improved in strength by the addition of more than one part of the matrice to four or five parts of the aggregate, the strength of cement concrete can be increased with each increase of the matrice until the respective quantities are equal.

In connection with the use of concrete in foundations, a system is sometimes practised of employing a better

quality for the bottom of the trenches than the top, or *vice versa.* But there is no advantage gained in so doing; if the bottom portion is made weaker than the top it has only the ground on either side to prevent it from bulging or crushing, and having the most weight to carry should be composed of equally as good materials as the upper part. Sometimes the best quality is placed in the bottom and the weaker on the top; if the ground has at any time to be lowered the weakest portion of the foundations may become exposed without any assistance sideways from the soil. The utter collapse of a large concrete engine shed on the Metropolitan Railway many years since was proved to be owing to the use of inferior concrete for foundations; the latter were levelled off for the superstructure in some places above the surface of the ground; the walls of the buildings were of Portland cement concrete, but the foundations were of ordinary lime concrete, and being unable to sustain the great weight imposed thereon were crushed, and the walls they were intended to sustain fell to the ground. Artificial foundations, too, are exposed to dampness and rainfall, and should be made of as good materials as the walls they have to support, so that in case the ground surrounding the latter has for any purpose to be removed, they will be capable of upholding the fabric as well as when propped up on either side with the natural soil.

Where the bottom of the trenches is sloppy, or water or mud prevails, it is better, after removing all that is practicable, to put in a few inches of clean, absorbent, dry core, such as engine clinkers or broken bricks, but with no sand or admixture of fine materials to create capillary attraction; if deposited on a wet, dirty bottom, and sand is intermixed with the dry core, the water and mud will, as a result, be partly drawn up from capillary attraction, and partly forced up from reaction through the concrete being thrown violently on it.

Care should also be taken, if the sides of the trenches are friable, or what workmen call "crumbly," that the con-

crete is not tipped or thrown against them, and so break away the loose soil and cause it to become intermixed therewith. If the sides are loose it is better to stand some boards against them, lifting or removing the latter by degrees as the concrete is being filled in. This is assuming they are not planked or waled, and stretchers are employed to keep the waling planks in position, a common occurrence in loose ground, but a detail which does not come within the scope of this article. If the concrete has to be deposited in water which cannot be pumped or otherwise kept out until the concrete is in place, it should be performed by means of buckets with loose bottoms, having catches on the outside with cord and trigger attached; when a bucket with concrete has nearly reached the required position in the trench, the cord is pulled, the bottom opens out, and the concrete drops in its place. A heavy iron weight and cord may be sometimes employed to advantage, for use as a punner or rammer, the cord taking the place of a wood handle. It not only compresses the materials, but distributes the unavoidable small deposits of concrete, causing them to become massed together.

When concrete has to be deposited in running water, sacks or bags are sometimes used, made of jute bagging tied tightly together at the mouth, and holding as much concrete as can be easily handled and tipped in the water from a stage or platform, and immediately over where it is required. The bags should not be filled tightly, otherwise the concrete will be unable to adjust itself to an uneven bed when it reaches the bottom. The bags of concrete pack themselves closer together, roughly interlock each other, and fit the irregular bottom much better than may be anticipated. Reasonably, the bag material does not adhere so well as the concrete itself would, but the matrice permeates it, and amalgamation ensues.

In submarine engineering works the deposition of concrete in this way is performed on a gigantic scale, vessels being constructed purposely with hoppers or

hatches to open and admit of the concrete being dropped through.

When buckets with loose bottoms or the bag system is adopted, it is sometimes the custom to only mix the matrice and aggregate dry, leaving the water in which it is to be placed to unite the two, but this is an error, as the matrice in a very fine dry state is dispersed by the force of the water unequally among the aggregate, some portions of the latter not receiving any, while other portions obtain more than is necessary; the better way is to use as much water only as is essential to cause adhesion of the particles. Other experienced practitioners in forming foundations in water allow the concrete to obtain its initial set before lowering it, and this certainly helps to prevent water from disturbing the matrice, and with but little diminution of the ultimate strength of the concrete.

For the construction of the breakwater at St Helier in Jersey the aggregate for foundations was put in dry, and pipes 3 inches in diameter with large hopper heads at top, led from the top of the water to the rubble, down which cement grout was poured. The grout was kept flowing until the diver, who was at the bottom, saw the grout rising to the surface of the foundations, when the tube was moved to another position, usually 10 to 12 feet distant.

When a building settles, or the walls crack from inherent weakness in the natural or artificial foundations, it was customary at one time to underpin the walls with lime concrete deposited in place as soon as made, the lime being fresh or hot, under the assumption that the concrete thereby expands and is pinched or tightened in the excavated ground prepared for it, and so upholds the walls. It is out of the question to suppose that the aggregate swells, and if the matrice expands, whether it be lime or cement, it will not only contract again but the concrete itself will blow and be rendered valueless. This can easily be tried by depositing some concrete made with fresh ground lime or new cement in a rough box or packing case. In the

course of a day or so, if the box is not already forced asunder by the concrete, take it apart and the concrete will probably crumble into fragments. If homogeneity in concrete is wanted anywhere it is in underpinning old walls where it has, as a necessity, to be deposited in lengths of 4 or 5 feet at a time, and as a result the best materials and most careful execution are of the highest importance, for the building may be said to stand on a series of independent concrete piers, and if these piers have insufficient strength to hold together they cannot carry a heavy building. It is a simple matter to make good—as it is termed—or solid between the top of the new foundations and the bottom of the old walls, by slate wedging or liquid cement grout, the latter as a rule making the soundest work; a combination of the two is sometimes practicable and preferable.

When a layer of concrete is about to be deposited on another which has been recently executed, water should be poured thereon to facilitate adhesion, and if any dirt or dry rubbish has accumulated it should be first swept off with a broom, and water from buckets thrown violently over the surface to wash out the smaller particles of foreign matter which have lodged in the interstices of the concrete after it has set.

It is very desirable to get the concrete for foundations in with as little delay as possible, that it may become of a monolithic character, and instead of filling the trenches to irregular heights at different points, to deposit the concrete in uniform layers, so far as may be found practicable, but if possible not less than 12 inches in depth or thickness at a time. It is better to fill in 100 feet lineal of trenches 18 inches deep in a day, than 50 feet 36 inches deep.

No rule can be laid down as to the depth of concrete necessary; 2 feet of good concrete is far better than 4 feet of bad, and the nature of the soil upon which it is deposited should also be a guide in this respect. Pot holes, or soft places, and an uneven and unreliable stratum,

will of necessity require good concrete and more of it. But it often happens that a larger amount of concrete is used than is actually required, simply to fill up the trenches to a certain height, and, as a cheaper material, to save brick or stone. It is in cases of this kind where the tendency so often occurs to use inferior concrete.

We seldom find any clause in a specification for concrete in foundations, stipulating how long it must remain before commencing to load it with the walls to be built thereon; but it is an important matter, more especially where it is intended to run a building up quick. When concrete foundations have been completed, the upper portion rapidly consolidates and hardens, and within a day or two, apparently, any reasonable weight can be placed thereon; but this is not so, as the atmosphere is an important factor in hardening concrete, and in proportion as it can act on the latter, so is the set hastened or retarded.

The better the concrete, so far as homogeneity is concerned, the more difficult for the air to permeate, and in the case of foundations, the bottom and sides being encased with the surrounding soil, the delay is still greater; there can be no doubt, however, that the hardness of concrete is ultimately increased by this retardation. I once had to remove a piece of Portland cement concrete wall, 4 feet thick, forming a portion of a church tower, which had been deposited in place several weeks; the centre might have been pulled asunder with slight exertion, and as the concrete approached the outside of the wall, so it increased in hardness.

This points to the danger of loading foundations too hurriedly; they may not crush or collapse under a heavy weight, but the particles of the concrete are strained and disturbed, and the strength of the foundations reduced.

The old-fashioned way of putting in the foundations of new buildings during the autumn, well protecting them

from frost during the winter, and commencing building operations in the early spring, is a more sensible arrangement than the modern practice of concreting the foundations one week and commencing to load them the following, but which modern practice often renders necessary.

CHAPTER VI.

HISTORY OF MONOLITHIC WALLS AND APPLIANCES FOR BUILDING MONOLITHIC WALLS.

AS a wall-building material there is but little evidence of the use of concrete to any great extent in olden times other than as a core between facings of some other materials. The construction of mud, clay, and cob walls between planks or boards is a very ancient process in this country, similar to the tapia walls of Spain, the pisé walls of France, the adobe walls of Mexico, and others, and must have been practised in very early times, perhaps coeval with wattle and daub. Cob walls were very common where some kind of unctuous clay and chalk were procurable, up to within the last sixty years. They were very susceptible to frost, necessitating stone or brick foundations and overhanging eaves to keep them dry, but they were warm and rain seldom penetrated. "Mud walling" and thatching were usually combined as one occupation in rural districts, but both have gone so nearly out of use that skilled workmen of that class are not often met with. It is not unlikely that owing to the objections to mud walls, lime concrete must on occasions have been substituted for cob or mud to fill in between the boards, and it is quite possible that isolated buildings with walls of this kind exist in out-of-the-way districts where lime, gravel or stone chippings were available.

Professor Middleton says the ancient Romans had five different methods of employing concrete. The one usually adopted for monolithic walls was to fix wooden posts in

the ground about 5 feet apart, and nail boards thereto so as to form a trough, into which the soft concrete was deposited. As soon as the concrete had set sufficiently hard, the boards were removed and fixed higher, and so on until the top of the wall was reached. This description would apply to most of the concrete walling executed at the present time.

In a work called "Santa Domingo and Hayti," by Samuel Hazard, published in 1872, it is stated, with reference to the buildings of Domingo: "The method of making the walls is simple and economical; the glutinous earth of the vicinity is mixed with lime, and sometimes, as in Cuba, with powdered stones; frames of plank are then made in the desired form, and these are filled with layers of the composition, sand and lime being added. The whole is then moistened with water, well pounded and kneaded and allowed to dry, when the mould being withdrawn leaves a firm solid wall, which on exposure to the air becomes as hard as stone. Even the walls of the city are built in this way, and the walls of the older houses are constructed of a similar material."

At Badajos in Spain the walls of the castle and fortifications still show the marks of the boards used to form enclosing panels; so that no matter in what part of the world, there is evidence that concrete as a wall-building material was well known and largely used many hundred years since, long before other artificial substances now recognised as well-known materials of construction.

As, however, Portland cement was unknown, concrete had lime for a cementitious constituent; but its excellent quality, the regularity and evenness with which all the materials were incorporated, and the apparent knowledge applied in the selection of the component parts, resulted in the construction of buildings equal in strength and durability to many of modern erection.

We do not appear to possess any information of concrete being employed in this country for wall building in modern times further back than about seventy years, when Captain

Moorsome, an engineer, constructed a house of lime concrete about fifteen miles from Gloucester, and which is now, or was a few years since, still standing; after that Mr Ranger erected the College of Surgeons in Lincoln's Inn Fields and several houses and shops with a similar material and with a fair amount of success. In 1859, M. Coignet took out a patent for a species of concrete or *beton*, the name by which it is still known in France, but where the process of mixing the ingredients was somewhat different to that practised in this country, the lime or cement having first the sand and water added so as to form a weak mortar or "grout," in which state it was poured upon the gravel.

M. Coignet erected a number of buildings on his principle: a full account of the erection of one, a railway station, appeared in the *Builder* and in the *Engineer* for the year 1859. The material, called by the inventor "*beton aggloméré*," had ordinary lime as a basis, and the principal points observed were to avoid excess of lime, and to employ a very small quantity of water for mixing, then to subject the mass to a large amount of compression or beating. For wall building, temporary wood encasements were used and small portions of the materials were cast therein at a time, workmen then gently tamping or ramming them until they were thoroughly consolidated. There does not appear to have been much novelty in the process, great care in dealing with the work being the principal factor.

M. Coignet stated at a public meeting in Paris that he had erected many buildings with *beton aggloméré* one being a house three stories in height, 60 feet by 40 feet on plan, in which every part—walls, floors, roof, string-courses, mouldings, &c.—was composed of the material, and without bond iron or lintels of any kind. The component parts of the concrete were:—

Sand, gravel, and pebbles - - - - -	8 parts.
Clay, burnt and powdered - - - - -	1 „
Cinders, powdered - - - - -	1 „
Unslaked hydraulic lime - - - - -	1½ „

The cost was stated to be 4s. 6d. per cubic yard in some parts up to 10s. 8d. for others. The description of the materials and the cost of the work read strangely at the present time. The house was said to be near St Denis; it would be interesting to know if it is still in existence.

In 1865 Mr Tall, a bricklayer by trade, brought the use of monolithic cement concrete walls into much prominence by the introduction of wood frames or movable panels for casting the concrete, and to the fact that he received a commission from the Emperor of the French to build several concrete cottages at the Paris Exhibition in 1867, and which created a widespread interest in this form of construction. Unfortunately Mr Tall published such absurd statements as to the strength, cost, and easy application of concrete by means of his frames, and which turned out quite fallacious, that they almost entirely stopped its adoption, and even now it has not altogether retrieved the good name it should have as a wall-building material. As an instance, the following is a copy of a statement he made and published as to the cost of building some cottages near Maidstone:—

	£	s.	d.
7 cubic yards of gravel at 2s. 6d. - - - - - -	0	17	6
7 cubic yards of Kentish rag stone for packing at 1s. 6d.	0	10	6
1 cubic yard of Portland cement, 16 bushels at 2s. 2d. -	1	14	8
Labour per cubic yard, 15 at 2s. - - - - -	1	10	0
Superintendence, 15 cubic yards at 6d. - - - -	0	7	6
Total cost of 15 cubic yards - - -	£5	0	2

Nothing is said about the cost of the apparatus, except that it was purchased for £100. The concrete was to be made with gravel as the aggregate, and Kentish rag stone bedded, or packed into the soft concrete—not always advisable in thin walls, and certainly not to the extent of 100 per cent.

As will be noticed, the cement was supposed to form a portion of the measurement, whereas it is, as a matter of fact,

entirely disseminated in the interstices of the aggregate, and the concrete itself would from shrinkage when wet measure 5 to 15 per cent. less than the aggregate alone.

It will be noticed that Mr Tall calls a cubic yard of cement 16 bushels, but it is 21 bushels, and, strange to say, the formula as given was copied into Laxton's price book at the time as the basis on which to estimate the cost of concrete walls.

The strength of concrete Mr Tall modestly put down at ten times the strength of brick walls of a similar thickness. Persons interested in economical buildings had walls, and floors too, constructed in concrete under the impression that so large a margin of strength would allow much liberty to be taken in the method and materials of construction. As a result, numerous accidents and several deaths occurred through walls and floors collapsing.

Mr Tall was challenged in respect of his invention being other than a reintroduction of a system of building walls which had been in use at various times for centuries; the same might be said, however, of many other so-called inventions. On page 526 of the second volume of Peter Nicholson's dictionary, a similar apparatus is described and illustrated, and Cresy's "Cyclopædia of Engineering," pages 725, 726, and 727, also gives several woodcuts, and information respecting appliances of a like character and for the same object.

Tall's success—from a commercial point of view, so far as the sale of patented appliances was concerned—soon brought others upon the scene, and Drake with an iron apparatus, and others followed in Tall's wake—most of them with a similar result—and sooner or later abandoning the manufacture and sale either from necessity or choice, for the simple reason that none altogether fulfilled the requirements essential for the construction of walls, viz.: (1) adaptability for varieties of plan or arrangement, (2) simplicity, (3) capability for being easily fixed and removed, (4) economy in cost, (5) portability, and (6) durability, and

which in addition would permit of the introduction of projecting string-courses, corbels, and other irregularities in the walls when in progress. No monolithic concrete appliances yet invented meet all these demands, nor does there appear to be a probability of any being invented; we must rest contented, therefore, with the nearest approach thereto, and with buildings of an unpretentious character, where concrete is to be entirely used for walls. This is one reason for concrete finding as yet, comparatively, so little favour as a wall material; another is the extravagant way in which it was brought into notice, with the object of making money thereby, and the disappointment which ensued when men who had both the means and inclination to adopt improvements in construction, found that the statements as to cost (one half that of ordinary buildings) and the facility for execution (by ordinary labourers with no previous knowledge thereof, and no artisans needed) were fallacious.

Attempts were also made by Tall to compel users of patented appliances to pay a royalty on every building erected with them, in addition to a large sum for the purchase; then there were difficulties, local and otherwise, and altogether concrete acquired for a time a rather unenviable notoriety. The mistake consisted in putting before purchasers all the apparent advantages, but none of the corresponding disadvantages of concrete and concrete appliances. They were led to assume that both were adapted for any kind of building, that concrete was capable of execution by any class of men with no previous experience, was economical in any neighbourhood, no regard being paid as to whether suitable local products for aggregates were or were not obtainable, nor to the competitive cost of local brick or stone walling, and that it was so strong that the margin of strength permitted almost anything being used for an aggregate and under any conditions; as a matter of fact, taking every kind of liberty with the materials and expecting to find equally good results. It was confidently

stated that wall building could go on in the most severe weather without the least injury to the concrete, that wall brackets could be projected and fixed to an ordinary 9-inch wall in progress, and scaffolding stages laid thereon without any approach to an accident, and other equally extravagant assertions.

The result was that many concrete walls were seriously injured by frost; others became distorted and shapeless by hanging scaffolds being attached thereto, acting as a lever to force them out of shape almost before the matrice had time to obtain its initial set; boundary walls of great length, 6 feet high and 6 inches thick, were erected with great speed at Teddington in Middlesex and blown down by a gale before they had consolidated sufficient to resist the wind pressure, and a great portion of a large concrete house four stories in height, building at Twickenham, fell to the ground in October 1868, while the remainder was so badly constructed that it had to be taken down. In 1872 a concrete building near Islington Green, in course of erection by a company called the "Monolithic Fireproof Company," collapsed, killing one man, and seriously injuring several others who had to be conveyed to St Bartholomew's Hospital. The company in question, with a view of showing what could be done with concrete, had formed a roof with that material; the *Building News* in some editorial remarks anent thereto remarked: "After a careful inspection of the ruins we can only express the opinion that the greatest carelessness has been shown in the composition of the concrete; masses of brick with a trifle of concrete have formed the defective portions of the fallen building; how any person could have expected such a building, in regard to the external walls, to have sustained the stress of the roof is past our comprehension." The man killed was the clerk of works, who—it came out in evidence—had been a farmer all his life up to within the previous two years, during which time he had acted as clerk in a financial office. Upon him the main responsibility rested, and the

jury brought in a verdict to the effect that his death resulted from total ignorance of his duties.

In 1877 a coroner's jury returned a verdict of manslaughter against a builder named Blandford, for building a house with concrete walls which fell to the ground and caused the death of a child, the concrete being described as of an execrable character. Reasonably enough, failures like these with concrete, so soon after its reintroduction as a wall building material, and at the same time that statements were being made public as to the extraordinary strength it was said to possess, resulted in far more notoriety than a dozen similar disasters with brick or stone walling would have caused. These mishaps were another contributory cause to check its use for a time.

It was discovered also that monolithic concrete walls after erection frequently disclosed ugly cracks, almost amounting in some cases to fissures, and although no great diminution in strength was supposed to result therefrom, they militated much in its disfavour. But this has always been an objectionable feature to contend with, and has influenced its use. Another difficulty is how to treat it when cast in troughs or frames, in a legitimate manner, so far as appearance goes. Stucco, or a coating of Portland cement, would appear to be well adapted for the material it has to cover, but this will not be entertained, as a rule, except for an inferior class of buildings, "cement stucco" being classed among the shams to be avoided.

There is the difficulty, too, of obtaining efficient supervision; not much interest is shown by mechanics in so uninteresting an occupation as piling up concrete in wood troughs, and ordinary labourers have, as a rule, preconceived notions on the subject which are with difficulty got rid of. Concrete wall construction, like other occupations, to be successful need be a distinct business.

Tall's appliances consisted of wood standards 6 to 10 feet in height, employed in pairs, one on either side of the walls to be built, and certain distances apart; these were

connected together with movable bolts and thumbscrews, the thickness of the walls being accurately determined by cores, or taper pieces of wood of the same length as the walls were required to be in thickness; the bolts were passed through these cores, and the latter were thereby prevented from being disturbed, and the bolts also from becoming fixed in the concrete; when necessary to remove the standards, the thumbscrews were taken off, the bolts withdrawn, and the cores being taper easily driven out. The movable panels or frames were 18 inches deep, and of

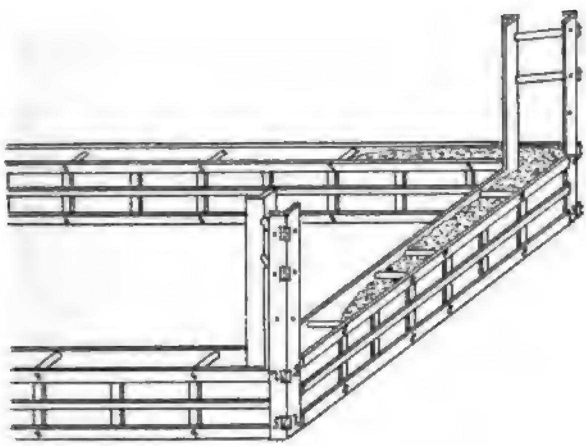


FIG. 7.—Tall's Wall-Building Appliances.

various lengths as required, and which were also secured with thumbscrews and bolts to the standards. Holes in the latter, equally distant apart, admitted of the panels being raised and fastened thereto as the work proceeded, until the top of the standards was reached; these were then removed and refixed by bolts passing through their two bottom holes and through the top holes left in the walling already executed. As this process could be repeated *ad infinitum*, any height of walling could be reached with the same amount of apparatus. For the corners of walls, angle

posts were used, and the end inside panels were necessarily the thickness of the wall less in length than the outer ones. Brackets secured to the walls with the same bolts used for the apparatus served as scaffold-bearers; flue cores or cylinders built in the chimneys, and withdrawn and re-arranged as the work proceeded, formed ventilating or smoke flues. Various contrivances for constructing chimney breasts and other projections were also provided, and the panels were covered on the concrete side with sheet zinc to prevent the concrete from adhering to the boards.

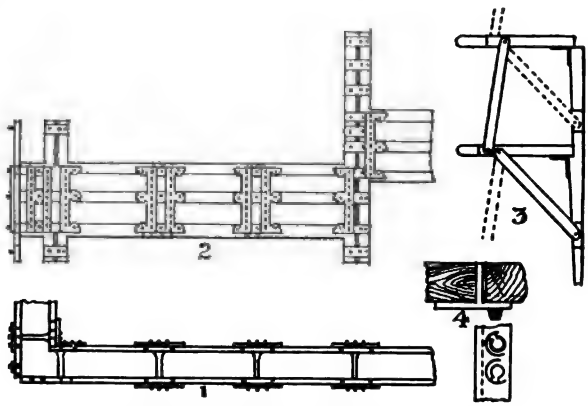


FIG. 8.—Osborne's Wall-Building Apparatus.

Osborne's apparatus was similar in many respects to Tall's, but the standards and movable panels were fastened in their proper position by bolts and rotary studs, instead of thumbscrews, and it differed also in many important points. (1), Fig. 8, is a plan of the appliances; (2) an elevation showing panels fixed at different heights; (3) brackets attached to the walls to form a scaffold; and (4) large scale plan and elevation of rotary stud fastenings.

Drake's apparatus (Fig. 9) differed materially from the two described; the standards, instead of wood, were of channel iron, the flanges of which, when fixed, were turned

towards the wall about to be built; mortices through these flanges, every 2 feet apart, admitted of bars of iron about 1 inch wide and ¼ inch thick passing through them; the bars, called "wall gauges," were pierced with holes 1½ inch from centre to centre to admit iron pins, which passed at the same time through small webs of iron riveted to the standards, and regulated the thickness of the walls to be built, the length of the gauges and the extreme distance of the pin-holes between forming the limit in this respect: as a rule they were supplied to construct walls 4 and 14 inches in thickness, and including every intermediate 1½ inch.

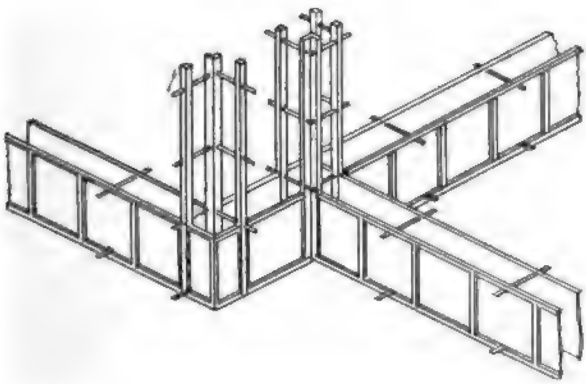


FIG. 9.—Drake's Wall-Building Apparatus.

The panels of sheet-iron riveted on a framework of angle and T-iron, were attached by malleable iron clips and pins or bolts passing through the latter, and also through the side flanges of the standards; the panels were made 2 feet in width, and consequently admitted of 2 feet in height of walling being constructed at one time. At intermediate distances between the standards the same kind of wall gauges were used, passing through the top and bottom angle irons of the panels. For corners of walls, angle plates were employed, which were secured to the end standards, but as they would obviously only serve for walls of a certain

thickness, there were "adding pieces," so that when the thickness was reduced, the adding piece was fastened to the inside, and when increased, to the outside angle plate. Projecting plates for constructing chimney breasts and other irregularities, telescopic plates for attaching to ordinary panels to make up the exact length of walling required, and collapsing flue-cores which admitted of being withdrawn from the concrete when the latter was set, formed other portions of the apparatus. The scaffold brackets were made of angle iron, and temporarily fastened to the uprights by bolts and nuts.

Lish's appliances were made of iron, and differed very considerably from any other, but the complicated system adopted prevented their use in any buildings where cost was a consideration; nor is it possible to give a brief description of their construction without copious diagrams. The Patent Office specification is accompanied by nearly one hundred illustrations and sections necessary to explain the principle.

As most other appliances were in general character a good deal similar to those illustrated, it is unnecessary to describe them, but they were nearly all composed of two principal portions viz., the standards, of any required height and rigidly fixed, and on which the accuracy of the walls largely depended, and the corresponding panels or frames, which were attached thereto, and served to confine the semi-liquid concrete until it had become sufficiently consolidated to allow their removal; the principle of construction was nearly the same in all, viz., building the walls the full height of the standards, then removing the latter and refixing them at the top of the walling already executed, and so on, until the full height of the building was attained.

The disadvantage that all concrete appliances possessed, and for which there seems no simple remedy, was, as before stated, owing to the standards being fixed in position close to the face or side of walls, so that considerable difficulty ensued if projecting cornices of stone or other materials

required to be built in as the work proceeded, for although there would be none, provided the standards could be so adjusted as to move forward and backward from the face of the walls, the want has not yet been surmounted in a practicable way. Lish's, and one or two others, were designed to meet this difficulty, but did not achieve success. The panels or frames are more easily dealt with in this respect, and therefore cornices intended to be cemented, and requiring only a core formed in the wall itself, cause little or no trouble, as the break or void in every case where a standard is fixed can easily be made good after it is removed, but with a stone cornice this would not be permitted, and special means have to be adopted to meet the difficulty.

The insertion of brick bond wherever required, and terra-cotta ornaments in the walls as they are built, cause much extra labour, and this accounts in a great measure for the discrepancies in estimates and tenders for concrete buildings; the more irregular the plan and the greater the amount of projections, or brick, stone, or terra-cotta insertions in the form of string-courses, bands, corbels, mouldings, &c., the larger in proportion will be the cost of the concrete walling, in most cases exceeding that of ordinary brickwork.

Made panels or frames to attach to the standards for enclosing the concrete—as in Tall's, Drake's, and Osborne's appliances—would be, no doubt, better than any others if they were required for buildings all of one shape, size, and internal wall arrangement, but, where no two may be alike, considerable difficulty arises in adapting them to walls of various lengths and thicknesses. To remedy this, short panels or frames from 3 inches to 2 feet in length, and called "adding pieces," "lengthening panels," "telescopic plates," and other names, were bolted to the nearest stock length of panel at hand, to make, as near as could be obtained, the length required; at best they were clumsy contrivances that unsatisfactorily answered the purpose.

All the appliances I have named have been, I believe,

abandoned, and, so far as I know, are not manufactured at the present time. It is many years since I saw any in use.

The inconvenience which each system of false work caused, and the inevitable delays that ensued when the portion required was not available, led me to make one for my own use of a simpler character, and which I improved upon from time to time. It was used for a large number of buildings in this country and in the colonies. But where intricacies and irregularities in the shape and size of walls occur, the cost of the false work will often exceed that of the concrete, but for walls of factories, warehouses, farm buildings and the like, concrete is the best wall building material.

CHAPTER VII.

MONOLITHIC WALLS, AND METHODS OF CONSTRUCTION.

CONCRETE walls are of various classes and many forms of construction. The monolithic is concrete poured or deposited in wood or iron moulds or troughs of the shape of the intended walls, chimneys, &c. Slab concrete walls are those built up on one or both sides with concrete slabs, and the cavity between the two filled up with concrete in a soft state. Block concrete walls are formed with solid or hollow blocks cast in moulds and allowed to harden. Faced concrete walls are—as the name implies—those which are faced on one or both sides with bricks, flints, or other suitable materials, the concrete forming a core.

The monolithic system is the one best known by reason of its cheapness, and although somewhat troublesome in practice is not the most difficult to deal with. It is capable of being carried on, under proper conditions, with great speed; this is often an objection, as it engenders a desire for that hurried style of erecting buildings so common nowadays, but which is fatal to good work.

The word "monolithic" conveys the impression that walls so-called are a single slab, or of the nature of a single stone, with no one part weaker than another; but this cannot be unless walling is carried on from commencement to finish with a rapidity that will allow no portion to become set before another is added thereto. This is impossible in an ordinary way, and although concrete users know that if they wish to pull down a concrete building the vantage

point is where the work has been suspended for a limited period, the strength even then of a good concrete wall is phenomenal.

The simplest way to form a trough into which to deposit the concrete in a soft state is—as would occur to most persons—to fix posts, or standards in the ground at intervals, and on both sides of the intended walls, the same as practised by the Romans, and which must be stayed or kept in position by wood struts or shores, and nailing boards thereto. The standards must be connected together by iron bolts, or wood, or iron hoop ties or similar means, and obviously they should be the full height of the wall or walls to be erected. As side strain on the standards caused by the pressure of soft concrete is prevented to a great extent by the connecting bolts or ties, there is no necessity they should be very large. Three and a half or four inches square is ample in most cases, and the ties or bolts may be every 3 to 5 feet apart. A similar system is adopted in some country districts for building mud or cob walls, and could not well be more simple for plain concrete boundary walls, but it becomes complex and unmanageable for buildings of any magnitude, especially if the walls are more than a moderate height. The arrangements for quoins, cross walls, chimneys, recesses, &c., also add to the difficulty.

The amount of timber, called "forms" or false work, required is considerable, and a heavy item in the expenditure, as it is not practicable to liberate the boards until the standards are removed, so that the whole superficial area of the walls has to be encased on both sides with boarding, which becomes so warped and twisted and indurated with cement as to be useless on completion of the building for anything but the roughest of uses. It has been said that boards of this description are applicable for the floors of the building in hand, but as a matter of fact they are fit for nothing, if not required for a similar purpose again, except for fencing or rough uses.

This method of building concrete walls is so simple as not to require illustrating.

An improvement consists in sawing the boards to a suitable length to fit somewhat easily in between the standards, roughly ledging them together to about 2 feet or $2\frac{1}{2}$ feet in width, and using them as movable shutters or panels. Instead of nailing the boards to the standards, they are kept fair or flush with the inner face or surface thereof, as shown by Fig. 10, which is a plan of a portion of a concrete wall, and an elevation of the same. A "fillet"

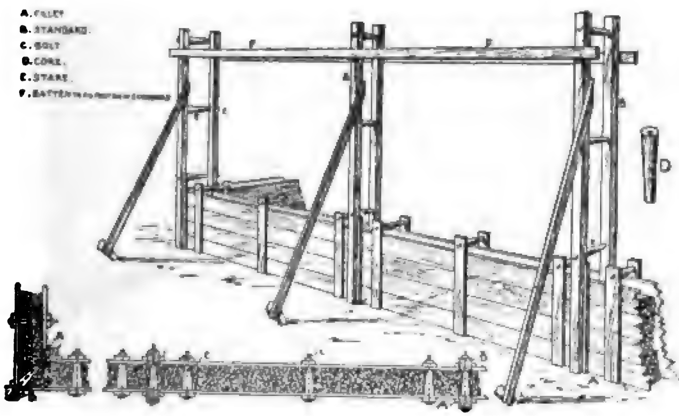


FIG. 10.—False Work for Monolithic Walls.

or strip of wood A, about an inch square, and of the same length that the shutters are in width, is tacked to the standards B, to keep the concrete from pushing out the shutters. Bolts C are passed through the ledges, and also through round wood cores D about $1\frac{1}{4}$ inch in diameter, having holes $\frac{1}{8}$ inch larger than the bolts, bored through from end to end, and just the length the wall is to be in thickness. The cores keep the shutters the correct distance apart. The bolts connecting the standards require similar cores and are for a similar purpose, and also to prevent the thread or screwed portion of the bolts from being injured

by the concrete when in the act of being driven out for the removal of the shutters. The latter should be made of boards about 7 inches in width, and 1 or 1¼ inch in thickness; if wider they are apt to get warped or crooked, if thinner they are not sufficiently rigid, and if thicker they are unnecessarily heavy; inch red wood imported flooring, or inch country cut red boards are suitable for rough walling, but thicknessed boards are better. A convenient width for the shutters is 2 feet 4 inches, *i.e.*, four 7-inch boards, but three are lighter to handle, and if the building is of considerable height are preferable in a general way.

The ledges, for shutters of about 10 feet in length, should be about 6 inches from either end, and the third one equally distant therefrom. The bolt holes should be 1½ inch from the bottom edge of the shutter, and an inch above the top edge, for which purpose the ledges should project 3 inches above the top of the shutter. The wood cores should taper about ¼ inch to facilitate easy removal. They are cheaper and better if turned in a lathe, should be made of hard wood, beech by preference, and previous to use soaked in water to cause expansion. The *modus operandi* is this: the standards being laid on the ground in pairs, and bolted together, are "pitched" in position and accurately stayed or braced to wood stumps driven in the ground—by means of a line for straightness, and a plumb-rule for perpendicularity; they are also kept the correct distance apart and upright, as towards each other, by means of a strip of wood F, the size of an ordinary slate batten, tacked from standard to standard. Obviously, a carpenter is the proper man to do this part of the work, as the form of the walls depends entirely upon the correctness with which the standards are fixed. This being done, the shutters are placed in position, the strips of wood nailed on the standards to keep them in place, and the bolts and cores fixed, when the trough is ready for the concrete mixers. The trough having been filled up and the concrete allowed at least twenty-four hours to set if Portland cement is the matrice, and forty-eight if lime, the

strips of wood are taken off the standards, the bolts of the shutters withdrawn, and the cores punched out with a beech punch. The loose cement and fine stuff adhering to the shutters are then scraped off as they lie on the ground, with a scraper—an ordinary garden hoe will do, or what is known as a ship's deck scraper is better—and afterwards brushed off with a bass or birch broom, but care must be taken not to roughen the surface of the boards with the scraper, otherwise a key for the cement will be formed; the cores are washed in a bucket of water, and the screw part of the bolt greased to prevent corrosion, which completes all that is necessary previous to refixing the shutters a lift higher.

But this time there is nothing to support the shutters; help is therefore required to hold them up on each side of the wall until the carpenter passes the three bottom bolts through and fastens the nuts thereon. The bolts rest on the top of the finished portion of concrete wall and support the shutters, allowing them also to lap or shut over the portion of concrete wall first finished the 1½ inch which there is between the edge of the shutter and the bolt. This 1½-inch lap is necessary to prevent the finer portion of the concrete and the cement from running through and causing waste, which would occur if the bottom of the shutter was level with the top of the finished concrete.

As the shutters are removable, so can the standards be, by taking them apart when the concrete walls have been raised as high as the former are in length, and refixed with the same stays or braces to any timber that may be adjacent, joists for instance, or in such way as the nature of the work and its surroundings suggest as most convenient.

But it is essential to carefully mark where the bolt holes are to be made in the standards. Let the top and bottom bolts be 6 inches from either end, and the others divided equally, not less than 3 or more than 4 feet apart. Let the standards be of any required length—if

over 10 feet they are inconvenient and clumsy—but so regulated by the width of the shutters that when the concrete wall has reached as high as the standards will permit, the top of the latter shall be about a couple of inches above the top of the shutters. This is very readily ascertained when the width of the shutters is known, and the lap or shut for each removal is allowed. The object is this—when the standards are refixed higher, the bottom bolt should pass through the same hole in the wall from whence the top bolt has just been removed, enabling the

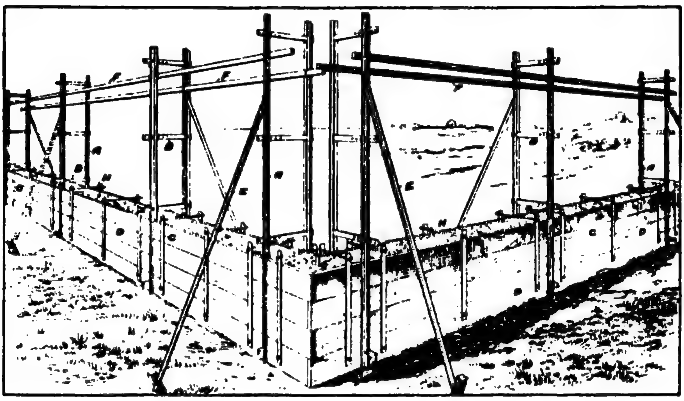


FIG. 11.—Potter's Wall-Building Appliances.

standards to be fixed at once to the wall with more ease and rapidity than otherwise would be the case.

Although rough and ready appliances of this character do very well for a single building in monolithic concrete, it is a different matter when a number have to be erected in various localities, and after numerous trials more or less successful, I designed one for my own use. The standards A A, Fig. 11, are formed of two light angle irons riveted together, and flat wall gauges B B with a series of holes therein passing through and fixed by means of pins or bolts and nuts, and acting as wall gauges. These enable the

walls to be constructed of any desired thickness. Wall cramps C C fixed to the bottom board D, and through which the wall gauges are passed, are necessary to keep the boards from bulging or bending. E E are light angle iron stays, and F F small strips of wood fixed temporarily thereto to keep the standards in position. Fig. 11 explains the general principle. They were used in the construction of a lighthouse for the Norwegian Government nearly thirty years since, and in South Africa for bungalows about the same time, and in numerous other places.

It is evident that the weight of sufficient standards, panels, adding pieces, &c., wherewith to build the walls of an ordinary house, must be considerable, and if this can be reduced by the employment of common boards, as described, which can possibly be used on completion of the work for rough flooring, fencing, or similar purposes, or sold for what they will fetch if not required for a similar object elsewhere, it must be the most economical in first cost and simplest in practice. Numerous patents have been obtained for this principle of construction by Corpe, Broughton, Macleod, and others, but none have met with much success.

An error of judgment was committed by patentees and vendors of concrete building appliances in stating that the latter required but little attention when in use, and that a labourer and boy were able to do all that is necessary in the way of fixing, removing, and refixing them as the walls progressed; in reality it is on the precision with which appliances of any kind are fixed that the accuracy of the entire construction depends.

The necessary qualifications for concrete appliances of any description to possess may be summed up as follows:—

1. They should not be unnecessarily clumsy or heavy, having regard to strength and durability, for it is quite possible they may be needed at places far apart and where the cost of transmission may be considerable.

2. They should be free from all complicated arrangements. Concrete apparatus made as a model—or shown

as an exhibit—with every care bestowed on its construction, is quite a different affair when exposed to the vicissitudes of weather, the rough treatment sure to be experienced at the hands of the lowest class of workmen, and the strain and violent usage consequent on the peculiar nature of the work.

3. Concrete appliances should be composed of as few parts as possible, and as far as practicable these should be interchangeable, and not consist of an almost indefinite number of stays, wedges, bolts and nuts, screws, pins, &c., and each of different dimensions.

4. Appliances should avoid as far as possible the necessity for large holes in the walls every few feet apart for cores or similar objects, as these tend to weaken the structure, require no inconsiderable amount of cement and labour to fill the cavities, and provide for drifting rains to find a way to the interior of the building.

5. The use of screws, and screw bolts and nuts, should be minimised, for the effect of wet concrete and exposure to the weather cause them to rust and become set, unless great care is exercised.

And lastly, the cost should be within reasonable limits, so as to induce building in concrete, instead of forming an argument on the part of the builder—so often the case—for the non-employment of concrete, of the heavy initial cost of appliances to do the work with.

The method of making and mixing concrete, conveyance to its destination, and hoisting and depositing, have been described in Chapter IV. In its application to walls in frames, care should be taken not to ram or compress it too violently for the desirable purpose of securing homogeneity, otherwise the latter may be obtained at the cost of bulging, or forcing out the encasing boards or panels and in this way bring about crooked or distorted walls, for which no remedy exists. A very light "stamper," or "prodder," which will penetrate the soft material, and open up a way for the semi-liquid material to compact itself into a solid

condition, is about the best way of rendering the mass homogeneous. A simple piece of iron 2 feet in length, 1½ inch in width, and ⅛ or ¼ inch thick, answers the purpose; one end should have a wood handle to hold it by, and the other end be pointed.

The concrete is better not deposited in long stretches of shallow depths, but the trough filled up its full height at once, and continued with all speed until an angle or break in the building occurs, to afford a suitable place to stop off.

When work ceases for the day, it is well to stop off the ends of the walls—as in foundations—with a board or slate or anything which will keep the end of the concrete solid, assuming that the layer for the whole of the wall is unable to be completed at once.

Packing, the use of which has been described in Chapter V., should be used with discrimination in walls, and where the latter are 9 inches and under in thickness not employed at all. The unsatisfactory condition of many concrete walls has resulted entirely from the too free use of "packing." It may be laid down as a safe rule that for walls not less than 10 inches in thickness packing may be introduced in rough single courses, but with not less than 6 inches in thickness of concrete between, and no portion of the packing material nearer than 2 inches to the outer and 1½ inch to the inner rough face, or surface of the wall, and no two pieces of packing a less distance than 5 inches from each other. For walls, probably flat stones make the best form of packing, old pavings for instance; but whatever it may be it should be clean, hard, and sound, the sides which have the largest superficial area placed downwards and rubbed or bedded into the concrete. The greatest care should be taken that smoky bricks from old chimneys or boiler settings are not used as packing, or inevitable smoke stains will sooner or later show through the plastering of walls.

The question of how rapidly the shutters or panels for

forming troughs may be moved upwards is an important one; under pressure the latter are occasionally filled during the early part of the day, and removed and fixed a lift higher and again filled the latter portion of the same day. This should not be unless absolutely unavoidable; the amount of time necessary for the frames or moulds to remain before removal depends upon the nature of the materials, state of the weather, and thickness of the walls, but even with quick-setting cement and a porous aggregate twenty-four hours should be allowed, and with lime as a matrice forty-eight hours if possible should be the minimum, especially in cold or rainy weather. The fact that frames can be removed without the walls tumbling down does not imply that they have sustained no injury, for the effect of withdrawing the supports previous to the concrete having sufficiently hardened is to split the walls into two longitudinal sections, and the fracture cannot be detected. Although with a large margin of strength no disastrous consequences may arise, yet the fact remains that the walls in places are in two thicknesses, devoid of bond and thereby deprived of a large percentage of their strength. The only way to ascertain if this is the case is to tap or sound the wall, and if it has not the ring of solid construction it is fairly certain to be divided; even if otherwise, the particles are disturbed and strained and the ultimate strength of the wall reduced. This factor in concrete construction is one which has received too little attention. Nor does the thickness of the wall make any difference in this respect; possibly a thick wall would be more likely to uphold itself than a thin one, but it requires a much longer time to harden, because the atmosphere takes longer to permeate.

A hard and fast rule, that no encasing panels or boards be removed until the concrete has been deposited therein at least twenty-four hours, would dispel all doubts on this point.

It comes within my experience that the concrete of a thin wall exercises as much pressure on the encasing panels

or boards as a thick one; this is readily ascertained by noticing the comparative strain on the shutters or boards during the time the walls are being built.

When the panels or shutters, whether rough boards only or purpose made wood or iron frames, are liberated they should at once be scraped to remove the portion of lime or cement—as the case may be—adhering thereto, otherwise it creates an affinity with successive deposits of concrete. Some builders apply a soap lather, or oil, to the face of the panels each time they are removed, to prevent the adhesion, but in wall building this is scarcely necessary if they are thoroughly cleaned, and the cement adhering to them removed each time they are used. A scraper, with a handle about 3 feet in length, is suitable for the purpose.

Smoke flues are formed by inserting taper or collapsing wood or metal cores in the chimney during construction, and withdrawing them as the buildings progress. If the aggregate is a suitable one this method will answer very well, but if composed of flint, or flint gravel, or materials of a similar nature that will calcine or split into fragments with heat, it is desirable to use terra-cotta, fireclay, or common red-ware flue pipes, either socketed or unsocketed, but the former are preferable. The extra cost is so small and the advantages so apparent, that it would be well to make a practice of always employing pipes, no matter what the aggregate may consist of, as perfectly smooth flues are thereby obtained without pargetting. For ordinary house flues, red-ware pipes answer very well, but where exposed to considerable heat the fireclay or terra-cotta tubes made expressly for such purposes withstand the action of fire better. Pipes 9 inches in diameter are of sufficient size* for houses under three floors in height, but

* The objection to 9-inch circular flues is, that they require sweeping oftener than those of a larger size. Undoubtedly for cottages and similar purposes where small fires are the rule, a better draught is the result. In some rural districts where it is often inconvenient to obtain

if more, then the tubes of an elliptical section measuring 10 or 12 or 14 by 9 inches are preferable. Where no pipes are used the flues should be carefully pargetted in the usual manner with hair mortar and cow dung, or with Portland cement and sand.

Fig. 12 shows a method of forming the throat of chimneys by covering the opening above the chimney bar with sheet iron, with a hole cut in the centre, or where necessary, and on which the flue is commenced. The advantages of this arrangement are that the sheet iron supports the concrete when in a plastic condition without any necessity for temporary wood supports, and the concrete is protected from the action of flames.

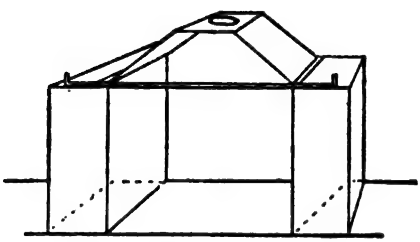


FIG. 12.—Chimney Throat Cover.

Although chimney bars may be and often are dispensed with, especially in narrow fireplace openings, it is not a desirable practice; bars caulked at each end and cambered or straight are advisable, owing to the high temperature which the adjacent concrete is subject to and the expansive force created, but which the chimney bar helps to control, but reinforced concrete lintels do almost as well.

No lintels are required for ordinary door, window, or other wall openings. All that is necessary is to keep the concrete in its place by means of temporary wood lintels, resting on upright props or quarterings. These lintels should be strong enough to prevent the weight of the first deposit of concrete from bending them, and this must be

a chimney-sweep, and the tenants are not liable to a penalty for their chimneys being on fire, it is a common practice to purposely fire them to save the cost and trouble of employing a sweep. For this reason alone it is desirable to use flue pipes as a lining.

determined by the width of the openings. If a reveal is required, then two temporary lintels are necessary, as Fig. 13. The use of slack blocks or folding wedges is advisable, so that the props may be removed without unnecessary violence; these should be used on the bottom of the props, as their removal causes less jar to the walls than if fixed on top; obviously the props should bear on blocks of wood or anything else substantial. Whatever form of temporary wood supports for upholding concrete for door or window openings or apertures of any kind is used, they should be first saturated with water, or better still, soaked in a tub of water to make them swell, or otherwise expansion will be caused by the water oozing from the concrete during the process of setting, and a tendency of the latter to rupture caused thereby will be the result. These remarks do not as a matter of course apply to the props or uprights.

FIG. 13. Temporary Lintels.

It is a good plan to embed light iron bars, caulked at each end, a few inches above the soffits or heads of window or door frames, and all walls should have iron hoops or rods embedded therein, every 1 foot in height, to remedy to a great extent the tendency to develop slight cracks, the result of climatic changes and contraction of the concrete.

With regard to rust, I have taken out iron which has been embedded for years in a concrete wall, and within about 3 inches of the surface with not a particle thereon.

This method of forming door and window openings in concrete walls is so simple and self-apparent as to need no further description. If the door and window frames are built in as the walls progress, much stronger and sounder fixing is the result, but it exposes them to saturation from the water contained in the concrete, and to injury from workmen. For a common class of erections—farm build-

ings and warehouses for instance—it is advisable to build them in, but this plan is scarcely to be recommended for a better class of work unless they are entirely cased to protect them from injury.

One of the advantages held out by patentees of concrete building appliances, of which latter scaffold brackets, or brackets to support scaffolds for workmen while filling the frames formed a part, was the great saving arising from no independent scaffold being needed. Except in special cases this bracket system of scaffolding should be avoided and for the following reasons: (1) The great strain thrown upon the walls at the time they have not attained 20 per cent. of their ultimate strength is an unfair way of dealing with them, and which no other form of building is subject to under similar conditions. (2) The scaffolds are, as a rule, for the sake of convenience and economy attached to the external sides of the walls of houses and other buildings, and the latter are thereby deprived of the support of division or cross walls, but, *per contra*, the scaffold acts as a lever to force them apart. (3) As the scaffold brackets are attached to the walls themselves or to the standards, it is quite impossible to finish the surface, whatever kind is proposed, unless the brackets are removed, and an independent scaffold becomes after all a necessity. (4) In most buildings the work can be executed, so far as construction is concerned, from the inside, with the assistance of tressels resting on the ground, or on the floor joists of the upper stories; but as there is no rule without an exception, so a bracket scaffold may sometimes be used to advantage without injury to the walls and may be considered as an occasional useful auxiliary.

The least amount of wood built into concrete walls, as into all other walls, the better; and the time-honoured custom of introducing certain timbers of one recognised size—as for example wall plates 4 inches by 3 inches, the only advantage in brick walls being that they occupy the same space as a course of ordinary bricks—may be advantageously abandoned.

As a matter of fact, the use of wood in the shape of fixing blocks, &c., can be entirely dispensed with in concrete buildings. In place of wood, blocks made from Portland cement and coke breeze can be inserted where provision for the fixing of joinery, &c., is needed; they hold nails and screws equally as well as wood, and with the undeniable advantages that they cannot decay, contract, or expand, and are fireproof, while the cost does not greatly exceed that of ordinary wood fixing blocks, or wood bricks.

Wall plates for floor joists may be dispensed with altogether, leaving holes in the walls for the insertion therein of the joist ends. The cores may be of wood, and somewhat taper, and soaked in water that they shall not expand when fixed, and render them difficult to withdraw.

Where the joists are under 9 by 2½ inches, common bricks placed edgewise, and afterwards broken in pieces with a hammer and chisel, so as to leave a cavity in the wall for the ends of the joists, is a common practice. A coke brick can be placed under the end of each joist, and the latter nailed thereto if desired, but no special advantage is apparent in so doing. The reason for not fixing the floor joists in the ordinary way as with brick buildings, *i.e.*, when the walls are the right height to receive them, is mainly because of the delay occasioned thereby in building the walls, and the difficulty created by the joists in arranging the encasing boards or panels; obviously the joists can be fixed in the usual manner if preferred, in which case it is well to place a piece of roofing felt, or anything of an elastic nature against each side of the portion of the joist built into the walls, otherwise the expansion caused by the wet concrete may tend to crack or strain the walls at these points during the process of hardening.

Ventilating flues may readily be made in concrete walls by means of wood or metal cores, or the insertion of common red-ware pipes, or ordinary rain-water pipes, and "dead work" or those portions of buildings that fulfil no purpose, but serve only to form the contour of certain parts, as in

chimney breasts and blockings for piers, recesses, &c., instead of being built solid, may have dummy flues formed therein in a similar manner, to economise materials and reduce the weight.

The practice that prevailed at one time of burying soil pipes, waste pipes from sinks, water pipes, &c., in brick walls, for appearance' sake, should on no account be practised with concrete walls, as infinitely more labour and cost would be incurred in cutting away walls built of concrete to discover leaks or stoppages, and making them good afterwards, than would be the case if built of brick; the greatest care, too, should be taken to avoid the necessity of any after alterations in concrete buildings, as the time required in making, say a doorway in a substantially built concrete wall, may be estimated to be quite four times as great as through a brick wall.

Wherever wood is temporarily employed for supporting or encasing concrete until it is sufficiently strong to support itself, care should be taken to leave room, if possible, for expansion, or otherwise to soak the wood itself in water previous to use. The covering boards of centres, for instance, should be of narrow widths, say from 4 to 7 inches at most, and with a small space between. The possibility that some of the cement may be carried through these open joints and lost is not borne out in practice, but a portion of the water not required for hydration will pass through the crevices in a clear state, and drip for some considerable time. If, however, very much more water has been used for making the concrete than necessary, some of the cement will undoubtedly be carried away with the water; this proves whether too much of the latter has been employed. Boards used for encasing concrete walls have sufficient freedom to expand or contract without doing any injury to the walls, as in no system would they be rigidly fixed to the uprights or standards.

The difference in cost between rough boards and machine thicknessed boards is so little that it pays to use the latter

for a better class of work. To prevent warping or twisting, it is advisable to alternately change the front to the trough side.

When the wall gauges, tie bolts, wood cores, or whatever is used to temporarily connect together the wood panels or boards, are withdrawn, the result is a number of holes or cavities in the walls which require to be filled up with cement. These should never be left unstopped till the walls are about to be plastered, or probably some may be overlooked, and a way for conveying rain or dampness into the interior be produced; but as soon as convenient after the walls are built, the cavities should be plugged with cement and sand (two of sand and one of cement is a fair proportion), not merely stopped superficially with a trowel, but pressed in with a taper piece of wood.

Where only a certain portion of the walls can be erected at one time, it is impossible to treat them in the same manner as if built with bricks, viz., by leaving "toothings"; or by "raking back," but indents can be left, by inserting wedge-shaped cores of wood, so not to form them of unequal depth. Hoop iron can be built in and left of sufficient length to tie into the walls that are to be hereafter built. If all walls can be erected at one time, it is by far the best plan, but where otherwise it cannot be considered a serious matter.

Whether temporary wood panels or patented appliances are employed, the first thing necessary is that they should be arranged so as to properly delineate the intended walls. Especial attention should be directed to the standards that they are perpendicular, and that the exact size and position of walls shown on plan are clearly defined; nor should the plea of "near enough" be accepted as a sufficient excuse for one wall being too long, or another too short, one leaning a trifle out and another in. It becomes therefore necessary to have the plans of all intended buildings drawn to scale, to avoid possibility of error, and better still for the fixer to have every dimension figured on the plans and sections,

that he may know where door or window frames are necessary, chimneys are required, party walls occur, &c.; it must be remembered that the rate of progress is much greater with concrete than with bricks, and that infinitely more trouble occurs in rectifying errors in construction—two reasons why detailed information in connection with the plans of concrete buildings should be quite clear. It also saves time and facilitates the operations of the "fixer," if the position of the standards is marked on the plans previous to commencement. A carpenter with sufficient knowledge of ordinary drawings to enable him to know when all parts of a building are in accordance therewith is the most fitting man to superintend this work, and with labourers to assist him in the more laborious portion of fixing and removing the appliances. The cost of this part of the work depends on the nature of the building to be erected—whether simple on plan or the reverse, whether of moderate height or of lofty proportion—and also if the walls are slight or massive; but the average cost may be reckoned at between a shilling and one and sixpence per cubic yard, exclusive of the value of fixing window and door frames and other incidental works that pertain to buildings whatever their materials of construction may be.

The class of men most suitable for mixing the materials and filling in the frames are necessarily active and able-bodied labourers; the work of itself is laborious and monotonous, and is deserving of fair recompense. The best description of men for the purpose are—as previously intimated—not ordinary town labourers used to builders' work, but, where they can be obtained, the better class of rural labourers who have no set groove to travel out of, and possess no hard and fast notions on matters pertaining to building processes, such as ordinary town labourers are sure to acquire after a preliminary initiation into the mysteries of mortar making and hod carrying.

Concrete is subject to a difficulty which prevails to a lesser or greater extent with all building materials, viz.,

expansion and contraction with change of temperature. This change of form has been put down to a peculiarity of concrete which other wall and paving substances are not liable to. But this is a mistake, for it is simply the materials of which the concrete is made that expand and contract, and their conversion into concrete in no wise affects this property of contraction and expansion. True, we do not get any, or but little palpable evidence of change of form in brick or stone walls, or brick or stone paving, but there is no mistaking it in concrete walls, or concrete paving. The reason is that the change is distributed so evenly throughout the multitudinous mortar joints of brick and stone work that it is imperceptible; brick walls built with cement will often show cracks here and there, usually put down to settlements, but which in reality are more often the result of contraction and expansion: if these cracks are watched, it will be found that they close in mild weather and open again when the temperature falls. Mortar-built walls never show the effects of contraction and expansion while cement-built walls frequently do, because mortar made with lime will withstand a certain amount of compression, while cement is practically unyielding, and, when set, incompressible.

The use of an unyielding material like Portland cement in jointing long lengths of coping or ridge tiles will cause the same thing; I have seen a massive brick pier at the end of a long wall, and against which the stone coping abutted, pushed more than an inch from perpendicular, and ridge tiles lifted completely off their bed and broken from the same cause. According to Hurst, the linear expansion by heat from 32 degrees to 212 degrees,—of granite is one part in 1,267, of ordinary brick one part in 1,818, and of fire-brick one part in 2,365, or $\frac{1}{8}$ inch in 24 feet, and this ratio would apply to concrete walls or concrete paving where the aggregates were of a similar nature, and *pro rata* to the amount of variation of temperature they were subject to.

It has been usual to charge the matrice with the cause

of expansion and contraction in concrete walls, but the quantity used is so small, if seasoned it is so little subject to change of form, and is so evenly distributed, that in my opinion it has next to nothing to do with the result, and this I submit is proved by the fact that good cement concrete, no matter whether used for walling, or paving, or other purposes, is unaffected in this way until a considerable change of temperature takes place, as explained in Chapter XI.

The fine hair cracks which are so often discernible in concrete walls arises as a rule, from the use of new, coarsely ground cement, or the surface of the cement drying more rapidly than the under portion. Naturally enough we find the results of expansion and contraction in the weakest places, viz., over window and door openings, or if a continuous wall without any openings, then at equal distances apart, ranging from 10 to 20 feet.

If hoop iron in continuous lengths, two or three in a course every 18 or 24 inches in height, is embedded in the walls, this change of form is almost entirely avoided. The foundations of walls do not show these cracks, accountable for by reason of never being subject to any sudden or perceptible change of temperature.

Concrete walls built in cold weather are less liable to cracks, while those built in summer are, on the other hand, more subject thereto. Another feature of the same subject is that lime concrete is less liable than cement concrete to give evidence of expansion or contraction, and walls a hundred feet in length, built of the former material years ago, show no sign of any change. As lime is credited with being of a much more expansive nature when made into mortar than Portland cement, this is a conclusive proof that the matrice in a lime concrete wall, like the lime mortar of a brick wall, is of a yielding and compressible nature, and as Portland cement is the reverse, we have to attribute therefore the cracks which cement concrete walls are sometimes liable to.

It is noticeable, too, that high concrete walls, or walls

heavily loaded, give but little evidence of contraction or expansion, a natural result of the counteracting force exercised by the great weight imposed thereon, and the transverse tie of floors, cross walls, &c., while, on the other hand, in low thin boundary walls they often appear of considerable size, and an almost uniform distance apart.

The upper portions of concrete boundary and dwarf walls are more disfigured by cracks than the lower, owing to the tie or key which the foundations, or portions below ground, give to the part nearest thereto.

Another reason why boundary and similar walls afford such direct and palpable evidence of change of temperature is, that they are exposed on both sides to extreme climatic influence, while walls of buildings are more protected, one side being subject to but little variation of temperature. Some curious remedies have been proposed for this misfortune of concrete, not the least being to make vertical joints in the walls of concrete houses by inserting a piece of wood or iron every 12 or 15 feet apart—practically building them in sections—so that instead of irregular cracks, less unsightly ones should be substituted.

But the simplest remedy is to avoid practising as far as possible all measures which induce this change of form, and the latter will scarcely be perceptible; for instance, the cement should be finely ground and thoroughly seasoned, the aggregate should be clean and of a proper consistency, and if possible a material not liable to much expansion from high temperature in its natural state, such as clinker from furnaces, burnt clay, brick débris, or slag from iron ore. The work should, if time permits, be suspended in very hot weather; I have found that concrete executed in cold weather, even in midwinter, if freedom from severe frosts can be depended on, not only makes the best work but is much less liable to give after-evidence of expansion—and the top of walls should be covered from the rays of the sun with empty bags, boards, tarpaulins or anything that will shade the concrete and retard its setting.

A free use of water thrown over the walls, and saturating the shading material, is in hot weather a desirable practice, and the work should not be rushed without there is a necessity for great speed in erection. Obviously, too, when work is suspended for a time, or the walls are for any reason stopped off at some part of the building, the latter should not occur at the weakest points, such for instance as near to door or window openings, for the concrete is then less able to resist the strain caused by climatic changes.

Over window heads, at the angle formed by the reveals in concrete walls, slight cracks may be often discovered, which arise from this cause. It is almost unnecessary to add that vertical "stoppings" in walls should never occur in the same vertical line, but break bond by not finishing a day's work at the same point that the lift below it was known to be left at.

Although I have never known serious consequences arise from shrinkage and expansion in concrete walls, it is fair to assume that the latter must be weakened to some extent, and the appearance is most objectionable; all necessary precautions should therefore be taken to prevent these.

In building boundary walls, or park or garden enclosure walls and the like, I have found that making concrete piers from 16 to 24 inches square on plan, every 15 or 20 feet apart, and afterwards building the wall between—which, by reason of the strength gained in using piers, may be less in thickness than otherwise—prevents evidence of change of form. A rough wood trunk is all that is required for forming the piers, and an indent should be left on each side, for the wall to tie or bond to the piers by inserting a piece of inch board of the same width as the wall is in thickness.

Concrete retaining walls, *i.e.*, walls which uphold or retain the natural or artificial ground on one side, are not so liable to develop cracks as ordinary walls, because they are exposed to climatic influence on one side only and so

maintain a more uniform temperature. All the same they do occur, and for this reason some engineers insert a thin piece of wood or sheet iron vertically, from top to bottom of walls, and at fixed distances apart. These are only carried a few inches into the wall, and fair or flush with the surface; when the concrete is dry they are withdrawn, and the space filled up with mortar or cement. This space probably opens and closes more or less when exposed to extremes of temperature, but is scarcely an eyesore in the sense that an irregular-shaped crack would be; it is thought that the shrinkage does not affect the wall beyond the space divided by the wood or iron strip but that the former retains a sound condition.

Sometimes where it is not practicable to store cement a sufficient time to season it, low walls will show horizontal fissures or cracks between each "lift" or layer of concrete, or where the latter has been left for a time before another deposit has been made. These are caused by the unseasoned cement swelling and bringing about the same result as the use of hot lime; we often see the lime constituent of the cement oozing through these cracks or fissures in the form of milk of lime.

Concrete retaining embankment walls of railways have many of these unsightly horizontal fissures.

With regard to the weatherproof qualities of monolithic concrete walls there is much conflicting evidence, but it is a sure matter that unless the greatest care is taken in construction, drifting rains will penetrate. It is so difficult to get a perfectly homogeneous wall with materials of all shapes and sizes, that strict reliance should not be placed upon concrete walls being watertight when left rough, or in the state they are built.

But there is this difference between the dampness which penetrates a brick wall made with inferior bricks, and the damp which passes through a concrete wall; in the former, moisture is driven through by the action of the wind, or transmitted by capillary attraction (as in a

sponge), permeating the entire body, or by the joint action of both.

But when rain finds its way through a concrete wall, it is by means of the crevices or crannies formed during construction, and not through the body of the aggregate. Portland cement indurates the materials forming the latter to an extent sufficient to render them almost entirely waterproof. Practically the former kind of wall is non-waterproof, while the latter is non-watertight, although the materials of which it is composed are in themselves waterproof—to an extent sufficient to apply that term to materials for walling purposes.

This may seem a distinction without a difference, as the general result is the same in both cases, except that the whole body of materials is saturated in one instance, while in the other the percolation of moisture is confined to certain parts only where crevices exist. The former must on hygienic grounds be far the worst. In my own experience of many years' occupation of several concrete houses which were cemented, or rough cast on the outside, and all in exposed situations, I always found them dry—much more so than the average class of brick houses, and certainly more equable in temperature and more healthful. The simplest and least costly way of finishing common walls for buildings, where appearance is of no great object, is called "rough trowelling," and is performed in this manner: cement and clean sharp sand in the proportion of one of the former to four of the latter—or more or less as may be determined, but one to four is a suitable proportion—are made into a stiff mortar in the usual way, and applied with a plastering trowel, exactly as ordinary plastering is performed; 4 to 6 superficial yards can be treated at a time, and with a plasterer's hand-float the mortar is thoroughly worked into the crevices of the concrete, but leaving no body or coat on the surface. After being well worked into the concrete it is smoothed over with a distemper brush and water, and is then complete. The concrete must have become hard

before this method of finishing is practised, or some portions of the surface may be loosened. This does not appear at first sight a very satisfactory system of treating concrete walls, but for warehouses where appearance is no great object, farm buildings, and similar erections where economy has to be practised, it is the best of any. The cement finishing forms an integral portion of the concrete, there is no coat of cement to be chipped and damaged, an intelligent labourer with a few hours' practice can do it, and it creates an almost unwearable surface; the cost is almost nominal, the labour and materials amounting to about 4d. per superficial yard according to circumstances. Moreover the appearance is not so objectionable as might be imagined; a handy labourer when once he has acquired the knack will often render it in appearance but little inferior to cement stucco of an inferior class, such as one often finds when executed by a bricklayer.

I have done the inside walls of mechanics' and labourers' cottages in this way, and when coloured they are in many respects better than ordinary plastered walls, because they are undamageable and the surface being non-absorbent to a great extent the walls are more healthy.

A bricklayer or plasterer should—previous to the rough trowelling being commenced—plumb and cement all reveals of doors and windows; and the addition of a narrow band of cement, say 3 to 4 inches in width projecting about half an inch from the surface of the walls, to all quoins and angles and all window and door openings, adds very much to the appearance and but little to the cost.

Window sills can be formed in the usual way after the walls are finished with cement, stone, cast concrete, or brick sills, as may be thought desirable.

With large blocks of farm buildings and erections of a similar class in the building of which cost is an important factor, and which are designed for use and durability in preference to other considerations, and where the inside

and outside of all walls together form a very large superficial area to be treated in some way or other, this system of rough trowelling is the best method that can be adopted. It may be said that the concrete can be left untouched, but the filling up of unavoidable crevices on the surface of all concrete walls renders them stronger, and prevents rain from penetrating and all the evil results which follow therefrom, while the extra cost is but trifling.

Rough trowelling, with a band of cement projecting about half an inch from the surface of the walls, to all windows, doors, &c., in the way indicated, is far from unsightly, and when the colour is toned down by time has anything but an objectionable appearance, looking what it really is—monolithic construction—for with rough trowelling the custom of making false joints or masons' lines in the cement is not practicable.

The difficulty with appliances for forming monolithic walls on the continuous system is that they afford no means of introducing projecting surfaces without very considerable trouble, labour, and delay, and what relief therefore is intended to be given to concrete walls where Portland cement is objected to, seems to point to some system of sünk panel or flat surface ornament.

Sgraffito in panels might be advantageously used, or tiles in bands or panels, and the small depth of sinking in walls of ordinary thickness necessary for these would have little or no prejudicial effect on their strength. Small tiles or even mosaic work might be introduced by arranging the materials face downwards in shallow boxes the exact size of the panels, and filling up the boxes with fine concrete; the tiles and this backing of concrete together need not be more than 1 inch or 1¼ inch in thickness; recesses in the walls during construction would have to be left to receive the panels. For string-courses, friezes, &c., some such system might be inexpensively and satisfactorily adopted.

The introduction of brick quoins and dressings has not as a rule proved successful.

Round or oval pebbles inserted in a rough or rendering coat of cement after the appliances have been removed, is for country buildings an appropriate finish, especially if arranged in panels with a margin fillet or band of cement. Rough dash, or rough cast is also an inexpensive way of dealing with the walls of cottages, lodges, &c.; this may be done by mixing fine clean gravel and coarse sand with slaked lime or lime "putty," or cement—or cement and lime putty mixed, half of each, to a semi-fluid condition, and as its name implies, casting or dashing it on the surface of the walls; but the quoins should have a neat fillet of cement or some other material, for forming a sharp angle or arris, or they appear irregular and ragged. Rough cast may also be executed by applying a rendering coat of cement and coarse sand, in the proportion of one of the former to three of the latter by measure, and throwing shingles into it when in a soft state. In this case the shingles should be uniform in size, washed very clean, and not too heavy, or they may not adhere. This is very suitable for buildings where shingle of a good colour, or of various colours intermingled can be procured, and offers in conjunction with cement strings or bands and cement quoins an opportunity for appropriate methods of finish. Another way is to mix half each of Portland cement and lime putty, and three parts of clean sharp sand into ordinary plastering mortar, apply in the usual way, either in one or two coats, screed and straighten with plasterers' straight-edge, and when half or more set, stab with a stump, or nearly worn-out birch-broom. This has a very satisfactory effect. Better still is to fix in a plasterer's hand-float small points of nails about $\frac{1}{4}$ inch apart, and projecting $\frac{1}{4}$ inch from the wood, and pressing them in the concrete while it is soft, in a random manner. This is usually called "stabbing," and if well done, is both satisfactory and economical. I have found this method to be preferred for many purposes.

Stamping patterns on a rendering coat of lime and hair,

or cement, or even marking with the end of a trowel, is an economical way of treating an inferior class of buildings. Half-timbered erections of the usual description, filled in between the timbers with concrete to form cast, plastered, or stamped panels has been suggested; but these scarcely come within the category of concrete buildings. The objections, however, are—(1st) the difficulty and cost of obtaining thoroughly seasoned and suitable timber, and therefore the possibility of the wood shrinking away from the concrete, and admitting rain and moisture; (2nd) the application of the concrete in small pieces, rendering it costly and troublesome to execute; and (3rd) making the life of the building dependent on a perishable material and the most lasting of the two materials subservient to the inferior and weaker. This may be remedied, however, by building the wall with concrete in the usual manner, and inserting coke breeze fixing blocks in the soft concrete for nailing thereto a facing of timber about $\frac{3}{4}$ inch thick, so that in place of solid timbers they would be veneers. The advantages of this method compared with solid timber erections are—strength and durability of a monolithic concrete building; easy application and economy of cost; impossibility of damp penetrating and consequent dryness of walls and durability of the timbers.

The objections raised against the system would perhaps be want of thoroughness, and to a certain extent a pretence of being what it is not; but this can scarcely be a heavy charge, for no attempt need be made to give it an appearance different from what it really is, viz., wood, with rough cast concrete panels; and the small quantity of timber required would permit of seasoned oak being used and left unpainted. This way of timber facing to a concrete building has been tried, and realised, so far as cost, appearance, and facility for construction were concerned, the success that was fairly anticipated.

The best way of finishing monolithic concrete buildings is still open to discovery, and probably no one will deny

that success in this direction has not kept pace with the manner of dealing with it as a structural material.

With regard to the cost of monolithic concrete walls, a very important factor obviously is the cost of the matrice, and whether the latter is ground lime only or cement. Unground, or knob lime, as previously pointed out, is in every way unsuitable for concrete, unless very carefully slaked and sieved to eliminate the core, but ground lime, as it comes from the manufacturers and allowed to season, is the handiest and best. Concrete with ground lias lime as a matrice makes excellent walls, and in a general way it may be assumed that if built of a corresponding thickness to brick and mortar walls, the strength will be at least equal thereto and capable of sustaining a greater vertical and transverse strain, if made of the best materials. The proportion of lime to aggregate should be about one to five, or one to six.

No preparation is necessary, and the precautions to be observed are the same as with cement, *i.e.*, keep it at least three weeks before use after its arrival on the works, in a dry shed and on a wood floor, and thoroughly protected from moisture. Many years ago when the price of Portland cement was very high I used ground blue lias lime from Bridgwater and from Pylle in Somerset with equal good results in the erection of large blocks of farm buildings.

For finishing by the rough trowelling process, Portland cement and sand applied in the way described is preferable to lime.

The proportion of Portland cement to aggregate for walls varies with the nature of the work to be performed and the quality of the latter, but assuming it to be in every way good, then one part to eight is strong enough for any ordinary building, and immeasurably stronger than ordinary brickwork in mortar. If every care is taken to thoroughly incorporate the ingredients, and the cement is of the best quality, one to ten makes good sound walling, and even one to twelve has been employed with excellent results.

It must be remembered that Portland cement is of a much superior quality now compared with what it was thirty years ago, at which time one part to seven was considered good enough for all building purposes.

With the cost of the matrice—whichever it may be—delivered, and the aggregate ready for use, the approximate value of concrete walling is easily arrived at. Due consideration must be given to the diminution in bulk of the aggregate,* and to the inevitable delays which arise in different ways. The assumption that if a certain number of men can mix and deposit a certain quantity of concrete in a given time for foundations, they will be able to do the same or half the amount in the same time for walls, is a mistake; scaffold making, setting out, removing and refixing the appliances, fixing cores, window and door frames, &c., have all to be taken into account and allowed for. Moreover thin walls obviously take much longer to construct than thick ones, if measured cubically.

The cost of concrete for walls, when compared with other building materials, must, however, be so conditional that no definite comparison can be made, and it is not even suggested that it can always be employed with advantage, but there are some kinds of buildings for which it is more specially adapted than others, and in no instance is this so conspicuous as for landed estates, factories, &c. For farm buildings, labourers' cottages, &c., which are now required to afford more accommodation than formerly, but which give a money return quite inadequate to their cost, concrete is especially suitable; for unsheltered as the majority are by adjoining buildings, exposed to strong winds and drifting rains from all points of the compass, nothing short of hollow walls are weatherproof, except concrete. No other suitable material can be used that will find so much employment for the unskilled and surplus labour of rural districts, and in many ways it appears to be specially adapted for the erection of farmsteads. It forms excellent

* See Chapter XXI.

water troughs and tanks, pavings, floors, &c., for cattle—is invulnerable against vermin—is durable—will resist any reasonable amount of rough usage—and for the class of work named, it can in many cases be applied for but little more than half the cost of brick walls of equal strength. On hygienic grounds, too, it is far more suitable for live stock buildings than bricks, or the more porous building stones, as owing to it being non-absorbent, it is less likely to hold the germs of contagious diseases, while the cleansing and lime-whitening of concrete walls incur less labour than brick or rubble stone work.

On some estates there are, unfortunately for the owners, a large proportion of old buildings past repair and unfit for habitation or occupation, and the materials they are constructed with are in many instances useless for any purpose whatever; but by the aid of a Blake Marsden crusher and Portland cement, old brickbats, flints, and stones are indiscriminately converted into a material every way qualified for the reconstruction of farmsteads. And the plans of such buildings are mostly of the plainest character, free from irregularity or intricate design, giving ample space, but avoiding those peculiarities of construction that engender a larger outlay than the rental of landed estates permit. Cheapness, strength, and durability are usually the objects sought for, and monolithic concrete with our present knowledge of its use, and the means of applying it, exactly meets these requirements.

In estimating the cost of concrete walls, there should be considered:—

1. The cost of each constituent delivered on the spot, ready for use, and their relative proportions.

2. The supply of water.

3. The character of the building, whether plain or intricate on plan, if blockings for cornices or projections for windows or other irregularities occur in the elevations, and the thickness of the walls (thin walls costing more in proportion to their bulk than thick).

As concrete walls, unlike brick ones, can be built of any required thickness, varying in single inches, it is usual to measure and estimate for their construction by the cubic yard. The practice is simple in measurement, easily calculated, and universally understood, and the reduced standard rod, square, local perch, rood, rod, rope, and endless other local terms of wall measurement it is to be hoped will eventually be ousted in favour of the much simpler cubic yard.

The cost of labour should vary but little in country districts; in towns it would depend upon the ordinary rate of wages; but, as a rule, for walls of average height and thickness in ordinary house construction, two shillings would be the minimum and three shillings the maximum value per cubic yard of mixing and depositing the concrete in place, including pumping water, and the erection and striking of tressel, or other form of scaffold.

A fair sum to allow for hire, or use and depreciation of the appliances for monolithic construction, is sixpence per cubic yard if the works are of any magnitude, and more for small buildings. With these data the probable cost of concrete walls may be arrived at with tolerable accuracy; taking imaginary prices for the materials and labour, the proportions being, say, seven parts of an aggregate to one part of Portland cement, we should get the following result :—

	£	s.	d.
1 cubic yard of clean gravel or other aggregate fit for use, delivered at - - - - - - -	0	4	0
2⅝ bushels of Portland cement delivered at 2s. - -	0	5	3
Labour of mixing and depositing - - - - -	0	2	6
Do. of fixing appliances - - - - - -	0	1	3
Use and depreciation of do. - - - - -	0	0	6
Per cubic yard - - - -	0	13	6

Here packing is assumed to compensate for the shrinkage in the concrete.

In deciding the thickness of external walls to be built

of concrete, good results have been obtained by adopting 9 inches for cottages, even in exposed situations, and 12 and 14 inches for buildings where 14 and 18 inches respectively would be the thickness if bricks were employed. With these comparative dimensions concrete is much superior to ordinary brickwork, both for strength and dryness, so that the actual cost of the former should not be compared for cost with other materials of equal thickness—but for strength. All concrete walls require some form of external finish, which common brickwork does not; but the latter necessitates arches or stone lintels to external window and door openings, and wood, or cast concrete lintels or discharging arches for internal openings, which together are a fair set-off against a plain way of finishing concrete wallings; but if something more than plain finishing is required for a concrete building, it may be assumed that something more than plain brick-work would be needed if it were a brick building.

As before said, although monolithic concrete is invaluable for walls, capable of resisting climatic influence and the roughest of wear and tear for generations, it must not be considered as adapted for every class of building and under any conditions. It can be most advantageously adopted for buildings of a plain and unpretentious character, such for instance as workshops, farm buildings, warehouses, granaries, and the like, and for boundary, enclosure and division walls, the party walls of brick or stone erections, and anything not too irregular in design or complex in arrangement.

For labourers' and mechanics' cottages it comes next in order of merit; but the thin division walls, chimneys, &c., create considerable labour in fixing the trough moulds and appliances, and make the cost more in proportion than the first-named class of buildings, for it must be remembered that it costs as much to fix the trough mould for a wall 4 inches thick as it does for one of 18. All the same, if a number of cottages are to be built together, or detached,

the walls will in most cases cost less than if of brick, flint, or stone, while their strength and durability surpass either. But if appliances have to be made or obtained purposely for building a single cottage, or pair of cottages of concrete, and the process is not well understood by the builder or foreman employed in their construction, any saving in expenditure or other advantages must not be looked for, but the reverse.

FIG. 14.—A Concrete House.

Simple designed houses, free from too many irregularities, gables, projections, and ornamental work, can be built to advantage if suitable materials can be had locally, and, on the other hand, bricks or stone necessitate much haulage. Fig. 14 shows a house of this description, built of slag in 1871, and at the rear of which is a large cheese factory. The floors of the latter are of concrete, the milk room being

covered with slate slabs (as it was found that whey disintegrated cement), and the cheese room over with cement only, the concrete being of an arch form resting on iron girders.

For dwellings for workmen in towns, in the erection of which the walling material is the largest item, concrete should find favour. It is just one of those purposes for which monolithic concrete is so well fitted; and as old buildings have, as a rule, to be pulled down to provide a site for new ones, and the materials carted away, a double advantage would accrue from the use of concrete, for the old bricks, stones, &c., could be crushed up on the site and re-used without any delay or preparation.

Summing up the *pros* and *cons* with regard to the use of monolithic concrete for walls, it may fitly be said that it cannot as a rule compete against bricks or other local materials—so far as cost is concerned—for buildings of intricate design, irregular plan, or where the total quantity of walling is but moderate in amount; on the other hand, there is nothing so economical, substantial, and durable, where materials abound, and the buildings are simple in design and of considerable magnitude.

As to the strength of monolithic concrete walls, caution is necessary with regard to any definite assertions, for the simple reason that they may be built by a careful practitioner with the same materials that a careless or unskilful one may employ, and yet be double the strength.

Mr Tall was wont to remark that concrete made of seven parts of an aggregate to one part of Portland cement was at least ten times stronger than common brickwork. But the sense in which this assertion was made was not apparent to every one. Some persons were thereby led to believe that a concrete wall 6 inches thick was equal in strength to a brick wall 5 feet thick, an assumption which no reasonable person could entertain; but, on the other hand, undoubtedly a concrete wall would withstand ten times as great a dividing or tensile stress as a brick and mortar wall of equal thickness.

The following experiment was made to test the strength of the concrete used in a certain building, and by no means specially selected or prepared. The aggregate was a mixture of broken bricks, quarry stone, and flints of a proper consistency, carefully mixed and deposited in place. The piece of trial wall was 5 feet in length, 5 feet in height, and 9 inches in thickness. A concrete foundation, 12 inches in depth and thickness, was prepared, and the proportion of cement to aggregate was one to eight.

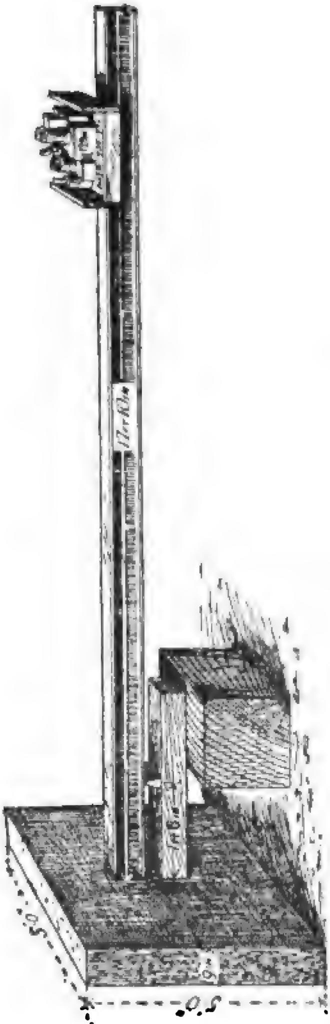


FIG. 15.—An Experiment for Strength of Concrete.

After a year had elapsed, a hole was made in the wall 16 inches from the top, and half way in its length, and an oak lever 20 feet long and 5 inches square was inserted therein, but gave way and broke asunder without disturbing the concrete wall.

An iron girder, 17 feet 10 inches clear of wall, was then inserted, but it lifted both wall and foundations bodily out of the ground, with the result that both were left dangling on the end of the iron girder. The wall was put back to its original position, and the lever and fulcrum arranged to

avoid a lifting purchase but exercise a dividing strain. The girder, which weighed 25 lbs. per lineal foot, was loaded with iron weights until the wall parted with a clean fracture its full length with a strain estimated at 3½ tons. Another illustration of the enormous strength of ordinary Portland cement concrete can be obtained from the facility with which openings can be made through walls without the use of needles, shores, or struts. Where alterations have been needed, I have cut openings as much as 14 feet in width, without a moment's hesitation, and on one occasion it was necessary to take down the party or division wall of an inhabited dwelling—on the ground floor only—leaving the upper portion of the wall 10 feet high, and a gable as well, intact. The building was 14 feet between the two flank walls, and the cross wall was therefore 14 feet long, and 9 inches in thickness throughout; the flank walls were 12 inches thick. The upper floor was in use as bedrooms while the lower portion of the wall was being removed. No needles or shores were employed, and the upper portion of wall—15 feet high to apex of gable—was left resting at each end only on the flank walls for several days, until an iron girder was placed under it.

It has been said that concrete walls more readily permit condensation than brick or stone walls. Possibly this is so until they are dry, but afterward I have never found any condensation, speaking from an experience of living in three concrete houses for over twenty-five years, the aggregates being respectively slag, river gravel, and crushed flints.

Nor have I on any occasion noticed that well-known musty smell which pervades houses of brick or stone after being closed and unoccupied for a time. Even if condensation occurred on a small scale, it is not harmful. Dr Richardson said that a readiness to condense moisture on walls was an advantage, insomuch as it was evidence of the atmosphere being damp, and a warning to the occupiers.

CHAPTER VIII.

CONCRETE BUILDING BLOCKS AND BLOCK-MAKING MACHINES.

CONCRETE blocks—solid and hollow—appear to have been unknown for building purposes until Mr Ranger, a builder of Brighton, obtained a patent in 1832 for what he called "Ranger's artificial stone." It is worth noting that until recent times artificial stone was the title given to all articles made of concrete, as the latter was considered so inferior a material that it was necessary to call it by some other name if its manufacture was to be commercially successful.

Ranger's stone gained some publicity by reason of the walls of the College of Surgeons in Lincoln's Inn Fields, some houses in Pall Mall, and other structures having been erected therewith. These appear to have stood the test of time remarkably well, and in course of recent alterations at the College of Surgeons it was found that the walls were perfectly sound, and apparently in no way the worse for wear.

Mr Ranger's system of making concrete was to employ hot or boiling water for mixing the ingredients, and powdered grey stone lime—Dorking or Reigate by preference—as a matrice. The aggregate was of various kinds, but principally sea gravel, broken flints, and masons' chippings. The inventor stated that, from experience, he found the best results were obtained by using 30 lbs. of an aggregate of a silicious or other hard kind, 3 lbs. powdered lime, and 1 lb. 12 oz. of boiling water. He mixed no more of the material at a time than was sufficient to fill one

mould, as the boiling water caused the concrete to set very rapidly; in ten minutes he was enabled to take away the sides and ends of the mould, and leave the block resting on the bottom only. The block so made was fit for use in a fortnight. Ranger rammed the material in the mould to drive out the air, and straightened the top side with a straight-edge. It may be interesting to give a plan and section of the very primitive mould used, and nothing could be simpler; if an ordinary carpenter was told to make a mould for a purpose of the kind he would probably construct it in an almost similar way.

Fig. 16 is a plan and section of Ranger's mould; *g h*

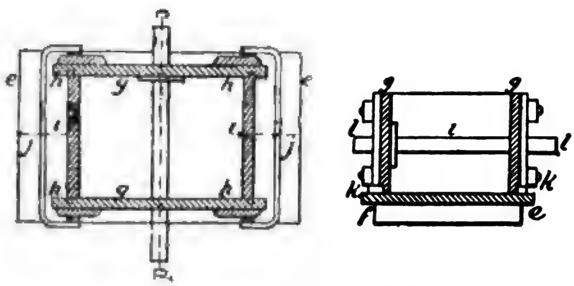


FIG. 16.—Ranger's Mould.

are the sides, and *i i* the ends; the sides have two upright grooves as shown at *h h*, *h h*, to keep the ends in position; the sides and ends are held together by means of four iron cramps *j j* (two at each end), between the ends of which and the sides of the moulds small wedges were driven, to keep them rigid; *e e* is the bottom of the mould, which is strengthened by ledges *f e*; *c d* and *l l* show a bar passed through the mould and left while the concrete is being deposited therein, and afterwards withdrawn. This was for convenience in handling or hoisting by means of an iron rod passed through the aperture, to which a hook or sling was attached.

About thirty-five years ago Mr Spencer Hayward, an

architect, patented iron moulds for concrete bricks. Each mould made twenty to fifty bricks, as preferred, and consisted of two sides held together by iron bars and pins, and having grooves into which iron divisions were made to slide. The mould was filled with fine concrete, the top struck off with a straight-edge, and after remaining for a few hours, the bars being liberated, the sides came away and each brick was placed carefully on a board to harden. The smaller mould for twenty-five bricks weighed 190 lbs. and cost £6, or £2. 10s. and a royalty of 2s. 6d. per 1,000 for all the bricks made. The inventor published a pamphlet in which he gave twenty-two reasons why his concrete bricks were superior to burnt clay bricks; nevertheless they do not appear to have been appreciated, or to have come into use to any extent.

Mr Henry Reid, in his treatise on "Concrete," in enumerating the advantages of the "block" system, says:—

"The labour required to fill, ram, and empty the moulds can be of the cheapest kind, and even women (!) and boys may be employed for that purpose when necessary. The blocks could be made at convenient intervals, and allowed to remain for months or years before being used. Less water can be used, and a larger proportion of gravel or other aggregate introduced into the block. In districts where employment of labour is intermittent and uncertain, the unemployed might be advantageously engaged in moulding bricks, which would readily find a market for house-building and other purposes. No imperfect block could by this arrangement be used, or a bad quality of cement employed, for sufficient time would be permitted to detect the shortcomings of the one and the other."

These acknowledged advantages were in practice, however, counterbalanced by the following disadvantages:—

1. Buildings constructed with solid concrete blocks or bricks necessarily require skilled labour to fix, equally as much if the blocks were natural stone or burnt clay; although it has been attempted to prove otherwise, it is

only reasonable to assume that blocks or bricks artificially made of concrete cannot be formed into walls in a proper manner with any less judgment or skill, because they are made in a different way and with different materials from ordinary bricks.

2. When concrete blocks are made from ballast, gravel, flints, or other hard materials, they cannot be sawn smaller, as stone could be, or cropped, as bricks can; and where cross walls intervene, chimneys project, or other causes necessitate bond-stones and short closers, or where indents, toothings, corbels, set-offs, gables, and other irregularities common to all buildings occur, blocks of the necessary size and shape would have to be moulded.

We have evidence of this in the attachments for moulding half blocks, quarter blocks, gable blocks, angle blocks, and others, which form a portion of the outfit supplied with block machines.

3. The strength of the monolithic system is not attained (unless cement be used for all joints), and the advantages therefore of increased density and resistance to crushing force is counterbalanced by the introduction of weak mortar joints.

4. The cost of labour alone in fixing the blocks would be approximately equal to the making and depositing concrete on the monolithic system, and the great advantage of diminution of skilled labour required by the latter method is not gained by the former. Although concrete blocks can be faced with a thin coat of cement previous to use, and so obviate the necessity of cementing or otherwise facing the work after erection, yet the cost of treating small blocks in this way is considerable.

5. The formation of chimney flues and throats, and the twisting and turning necessary in many cases would be an almost insuperable difficulty with concrete blocks made of some materials. All the same, where an aggregate is ready to hand for little or no cost, slag from iron mines, furnace clinker, or stone chippings for instance, solid concrete

blocks for special work such as boundary walls, &c., ought to find a market in this country more readily than is the case.

Concrete block making has been taken up in America in a systematic manner. So much depends upon the moulds, and the ease with which the blocks can be liberated, that their manufacture alone has become an important business. Wood for the purpose is almost useless; it lasts a limited time, warps and twists from the water used in making the concrete, and swells sufficient to render blocks of uniform dimensions impracticable. Concrete blocks, as at present used for wall building, are made hollow, and the reasons for this are apparent; they require less material than solid, are lighter and easier to handle, the interior of buildings are not so susceptible to changes of temperature, and dampness that might otherwise pass through the walls is prevented.

The materials used for block making require to be of the same nature as for other purposes for which concrete is employed, but much smaller, and to some extent according to one or other of the processes known in America as dry, medium, and wet or poured. With the former, sharp coarse sand forms the aggregate, and to which water is added sufficient only to bring it to a consistency that it will not exude therefrom when firmly pressed in the hand, but will retain its shape. This enables the block to be removed directly it is cast, or soon after, and the mould is at once available for another block. By the medium process the concrete is made from a larger aggregate of varying proportions up to that which will pass a ¾ or 1 inch mesh screen, and of a consistency similar to concrete used for general purposes. Wet or poured concrete is only used for ornamental work, where clean arrises and mouldings require to be sharp and perfect, and which is mostly done in sand moulds, or where undercut, jelly moulds, the fine concrete or cement being backed up by coarser stuff. With the dry process the sand must, or should be, of uniform

quality and colour throughout, and where certain neighbourhoods produce sand of this description blocks may be made to advantage. The concrete has to be tamped to ensure homogeneity, and this by hand is a tedious process. To remedy this, pneumatic tampers and mechanical tampers have been employed with success. No facing to blocks is necessary by the dry process, and this element of cost can be saved. The appearance—if a good colour sand is used—leaves nothing to be desired, and possibly it is the much better appearance than is possessed by common brickwork that is one of the causes of the extensive use of concrete blocks in America.

But blocks made by the dry process are more liable to convey moisture than by the medium, and as insufficient water is used to promote crystallisation of the cement—an essential for hardening—they are not so strong. Where a greater proportion of cement is used the blocks are necessarily stronger, and a possibility of conveying damp to the interior of the building reduced. That dampness is not unknown is in evidence by the fact of advertisements of solutions to make block concrete walls damp-proof being quite common.

As a rule, and because if cast in a mould no additional cost is incurred—or but little—an ornamental face can be produced for external walls, and this usually is a representation of rock masonry. To effect this the blocks are cast face downward, and the machines for making them are called "face down machines" in contradistinction to machines in which the side of the mould forms the face side of the block. A portion of the fine material sufficient to cover the "pallet," or plate on which the concrete rests, having been deposited in place, it is backed up by a coarser material—one to three or one to four—that would just pass a $\frac{3}{4}$ or 1 inch mesh, or the finer material if abundant can be used throughout. Blocks made by the medium process require to have a skin of cement, or cement and sand, plastered on the face of the

mould, usually one to two, which provides for a smooth surface.

Sand for mixing with cement for facing should, if possible, be dry, as if wet the particles have a tendency to cling to each other during the process of mixing. But the filling of the mould with the coarser aggregate—if the machine is a side face one—dislodges the facing material, and so a thin iron plate is used between them to protect the latter until the mould is filled, when it is withdrawn. This takes time, and is not altogether a satisfactory practice, and as a result face down machines are more in requisition. Light tamping is only necessary with the medium process, and the aggregate being larger as a rule, a less proportion of cement affords equal strength, but a cement, or sand and cement face is unavoidable.

In blocks made by the dry process, air imprisoned in the concrete readily escapes by reason of the innumerable vacancies between the sand particles. In the wet process, however, this is not so, and holes are sometimes made in the moulds for the purpose, and also to afford means for water not required for hydration to escape. The casting of blocks, or any form of ornamental work in sand is an easy matter by means of a wood or metal pattern, as in iron castings in sand, but is costly. When the blocks are removed from the machines they should be stacked for the air to pass round them, and remain so for not less than two weeks before removal for use; longer is better.

In America this process is called "curing" the blocks; here we call it by the more readily understood word of "seasoning."

Instructions for making, moving, and stacking blocks for seasoning cannot be more clearly stated than as contained in the trade booklet of the Waterloo Block Machine Company, and which are as follows:—

"Varying proportions of clean, coarse, and sharp sand can be mixed with one part of cement and give good results; but one part of cement to four parts of sand, or one

part of cement to five parts of sand, will give excellent results. If absolutely watertight work is required, the face of the concrete should be plastered on the side facing the block with a mixture of one or one-half parts of sand to one part of cement.

"Great care must be taken in mixing the cement and sand. This must be thoroughly done before any water is added. Never mix large quantities, but only so much as can be put in place within fifteen or twenty minutes of mixing. The sand and the gravel must be clean, coarse, and sharp; the drier the better. Mix at least three times dry and twice wet, tamp soundly into the mould, giving special attention to the corners and edges, as these are the vulnerable points of the block. Pallets must have sufficient strength to resist any bending in removing and carrying of the blocks. The least bending of the pallet will cause the block to crack, usually unseen in this, the green state.

"When the blocks have been placed in the racks many makers unfortunately consider them finished, but now comes the crucial work, 'curing.' This must be done under cover, in a building little exposed to outside currents of air, which cause the blocks to dry too rapidly. The slower the drying, the harder and tougher they will become.

"When the blocks are set sufficiently so that water will not wash the surface, they must have water, and plenty of it. Unfortunately, the too frequent custom of light sprinkling is only little better than none at all, as it causes a thin crust, leaving the bulk of the block with vastly insufficient water, and making a block of imperfect density and very liable to crack, owing to such uneven hardness. Blocks should never be allowed to dry out on the surface until the centre is thoroughly cured. Rack your blocks so that the water can be applied on all sides, and be sure that sufficient is given to permeate the centre of each block. The floor of the curing room should be of sand, and kept as wet as possible to ensure a damp atmosphere.

"Blocks should be thoroughly watered three times a

day—morning, noon, and night—for seven days. Do not remove from the curing room before three days, as this is the critical period, and during this time they must not be allowed to get dry. Unfortunately, owing to the necessities of block machines in requiring a dry mixture to prevent adhesion to the moulds, the cement mixture has less water than when used for any other purpose, and after removal from the machine the blocks are so placed that they tend to dry very quickly (the form of the block also hastens this result), so too much emphasis cannot be put on the necessity of giving them plenty of water. To properly do this requires great care and faithfulness, and if possible is more important than any other part of the manufacture; so we repeat, keep your blocks in a damp place for three days and give them plenty of water, and after you have given them what you consider sufficient, water them again thoroughly.

"The moment the surface of the block begins to turn white it is a sure sign that the blocks need water, and they should be thoroughly wet each time this is noticed. Remember they cannot have too much water, and if you compare blocks made in this way with those insufficiently watered, the difference is seen at once."

An objection to the medium process is that the blocks cannot be removed from the machine until the concrete has obtained sufficient strength to what is called "hold itself together"—a matter of hours, whereas by the dry process it is only the pallet that has to be kept unemployed until the block is hard enough to take care of itself, and so a certain number of pallets are required with each machine. Where block making is a business by itself—and there are many in the United States—the materials are usually mixed in a machine of which there are many types—hand and power. Necessarily hand machines are only adapted for a limited quantity of materials—half a yard or thereabout at a time—and unless they can be handled quickly this is as much or more than advisable, but a mixer

adapted for use with a small gas or electric engine performs the work better.

The quantity of water necessary for mixing can only be determined by practice; the nature of the aggregate has to be considered.

The variety of blocks and brick machines made in America and elsewhere is so large that it is only possible to illustrate a few, and to enable readers to obtain

FIG. 17.—Ideal Block Machine.

further particulars, if desired, the names and addresses of the makers are given. It does not follow that those illustrated here are examples of the best; it would require practical experience of each to form an opinion, but there is no doubt that the manufacture of block machines has arrived at a high state of perfection, and that where a large number of blocks is required it pays far better to purchase a machine than to make one of a rudimentary character.

Concrete bricks are used extensively in America, their use being dependent on the local cost of ordinary clay bricks. The "Ideal" block machine (Fig. 17), manufactured by the Ideal Concrete Machinery Company, South Bend, Indiana, U.S.A., is one of an almost endless number and variety by the same company. The illustration shows what is called a model E 24-inch machine, and is priced at about £60 of our money, but which includes fifty pallets, on which the blocks are cast and removed to dry for either rock or plain face blocks, and the necessary equipment for making corner blocks, pier blocks, quarter blocks, half blocks, gable blocks, &c. The agent for the sale of the Ideal block machines is Mr Matthew Wylie, 53 Robertson Street, Glasgow.

FIG. 18.—South Bend 20-Brick Machine.

Machines for making concrete bricks are shown by Figs. 18 and 19, and are manufactured by the South Bend Machinery Company, 1802 S., Franklin Street, South Bend, Indiana, U.S.A., and whose agent in this country

FIG. 19.—South Bend 10-Brick Machine.

is the Swansea Stone Block and Machine Company, New Cut Road, Swansea.

The 10-brick machine is said by the makers to be capable of turning out 3,500 bricks per day by two men, and the larger 20-brick machine over 4,000 per day by two men. This does not include mixing the materials, and removing and stacking them to season.

FIG. 20.
Waterloo Block Machine.

Fig. 20 shows a machine for block making by the Waterloo Block Machine Company, of 101 East Fourth Street, Waterloo, Iowa, U.S.A. The makers say that two men mixing and tamping the concrete will make 200 blocks each 24 by 8 by 8 inches a day, and two more will wheel in stuff, take away, and stack them. A brick-making arrangement is attached to the machine, enabling solid bricks to be made as well as hollow, as may be required.

FIG. 21.—Brandell Block Machine.

The Brandell Block Machine Company (Fig. 21), 130 Dearborn Street, Chicago, U.S.A., makes face down block machines of various sizes. The blocks are mostly 16 by 8 by 8 inches, and possess 33 per cent. of air space or

cavity, and the price is stated to be £20, exclusive of the extra parts. The total weight of the machine and accessories is given as 1,000 lbs.

Fig. 22 is a 10-brick machine made by the Cement Machinery Company, of 10 and 11 Covley Block, Cartland

FIG. 22.—Cement Machinery Company—10-Brick Machine.

Street, Jackson, Mich., U.S.A. The manufacturers say that with their block machines two men are turning out 210 blocks 32 by 10 by 9 inches, equal to 350 cubic feet, or 420 superficial feet of walling per day, and that the making of concrete blocks with their machines is quite a pleasure, an assertion which should carry a good deal of

weight in influencing their adoption in this country, where there is but little evidence of work of this kind constituting a pleasure. Nor can it be expected, I suggest, if two workmen can turn out 420 superficial feet a day—9 inches in thickness—as an average day's work.

Fig. 23 is an English-made machine by the Concrete Machinery Company, 18 Water Street, Liverpool, and is called the "Pioneer Junior Machine." The prize block

FIG. 23.—Pioneer Junior Machine.

concrete cottage at Letchworth was built with one of these machines, and the company say that they are in use in forty counties in the United Kingdom.

The Hercules machine, Fig. 23A, allows of it being operated either singly or doubly. The length of the blocks can be reduced by adding end plates, and it is claimed that one size pallet can be adjusted for any size blocks. This machine appears to be largely used in the United States.

The manufacturers are the Century Cement Machinery Company, Rochester, U.S.A.

Whether the use of concrete blocks will eventually be as general in this country as they appear to be in America is doubtful. The main objection to their use is identical with that of terra-cotta. Each block must be of the correct dimensions; if there happens to be one wanted more than is available for a certain portion of the building, the latter has to wait until it has been moulded and seasoned. The formation of bays, gables, piers, corbels, &c., increases the

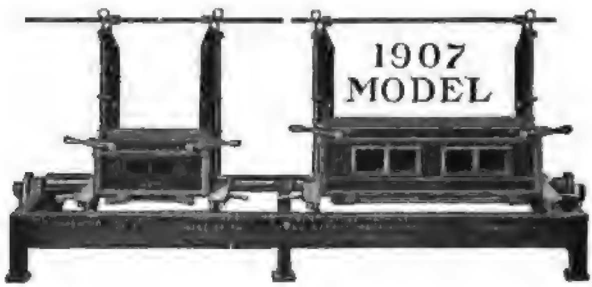


FIG. 23A.—Hercules Block Machine.

difficulty. For large buildings of an unpretentious character they may be used possibly to advantage, but for small ones, where perhaps no two are alike in shape and size, there is bound to be some trouble. All the same, if certain things are successful in certain places they should be in others, even if in a minor degree. On landed estates —if anywhere—concrete blocks ought to be useful in building park walls, boundary walls, unpretentious ranges of farm buildings, &c. If the aggregate was available on the site, their manufacture would employ surplus labour in the winter months when agricultural pursuits were at a standstill.

CHAPTER IX.

SLAB WALLS AND FACED CONCRETE WALLS.

THE weight of solid blocks of concrete proved a barrier to their general adoption for building purposes, and which led to making them hollow and filling the cavities with concrete, as described in Chapter VIII.

In 1875 Mr J. C. Sellars, a manufacturing chemist of

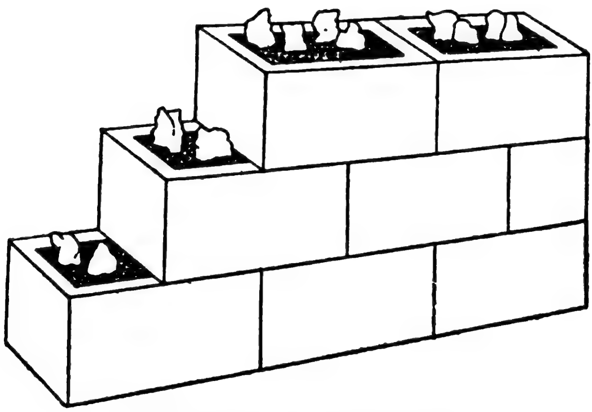


FIG. 24.—Sellars' Hollow Blocks.

Birkenhead, invented and patented a system of building by means of hollow blocks made as shown by Fig. 24, the hollows or cavities filled up with rough concrete. There were many variations in the way of bonding and interlocking the blocks, but the one illustrated is the simplest. Mr Sellars subsequently invented presses and dies for

making these blocks, and other devices, but so far as I am aware his inventions never obtained much support; he proposed to erect temporary buildings by piling up the blocks dry, one on another, and not filling the cavities, which he designated tent building, in contradistinction to walls built with coarse concrete, styled rock building. As with many other inventors, Mr Sellars appears to have

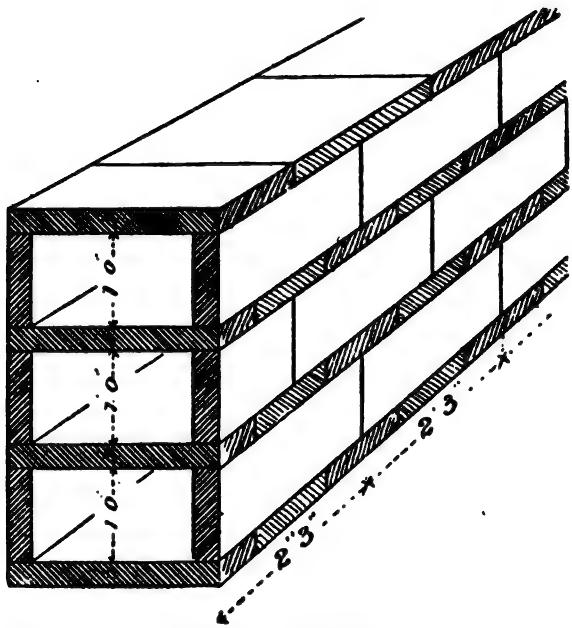


FIG. 25.—Cornish Slabs.

been over sanguine as to cost, for he claimed that taking ordinary brickwork as the standard, a profit of £220 could be made out of a £600 estimate.

Mr Sidebotham, an architect of Blackpool, introduced concrete blocks or slabs in 1876. They had two projecting ridges or lugs on the back of each slab, between which a dovetail groove was formed; into this groove a transverse slab was dropped, cement grout was run in the dovetail

mortices to fix the transverse slabs and the core was formed of concrete in the usual way. Iron or other metal ties of a small size were sometimes adopted in preference to concrete, the ends of which hooked into metal eyes cast in the slabs when in process of manufacture, but they never came into general use. Mr Cornish, a builder in Middlesex, in the year 1877, invented a system of block construction by forming slabs of a plain, flat description, building walls therewith by setting them up edgewise, similar to hollow brick walls. The slabs were made 2½ feet long, 1 foot wide, and 3 inches thick. The bonding was obtained by laying a course of the same kind of slabs flat between every vertical course, as shown by Fig. 25, which is a cross section of a wall.

Longitudinal bond was secured by bedding each slab of the horizontal course to cover half the vertical slab upon which it rested. Necessarily the bonding slabs were in length equal to the thickness of the walls. The inventor claimed that this way of building a wall afforded the best possible means for ventilation and warming by allowing the air to pass through certain of the apertures, which would of necessity pass all round the building, and fixing covered gratings or air inlets at any desired point, so that fire mains even could be laid therein. The difficulty of obtaining access in case of repairs being needed would, however, scarcely recommend waterpipes being buried in a hollow wall of this character. No doubt excellent and cheap walls might be constructed on this principle where materials were plentiful, and nothing could be simpler. In rural districts where materials are abundant, the manufacture of slabs of this kind would give work to unemployed and unskilled labour in winter, and bricklayers or stonewallers should be able to rapidly build walls of this description. But 3 inches thick would render the slabs too heavy to handle with facility; if properly made, 2 inches would be more convenient and of ample strength, or if reinforced, 1½ inch would be ample.

Mr J. J. Lish, of Newcastle, introduced about the year 1878 concrete facing slabs of a peculiar shape, which he

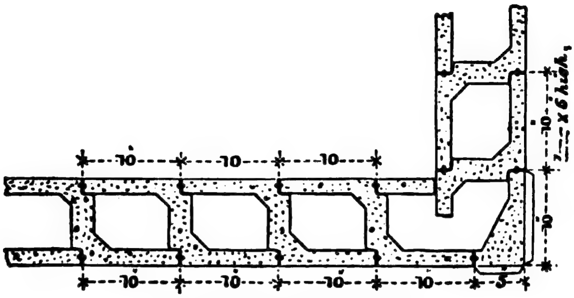


FIG. 26.—Lish's "Z Blocks."

called Z blocks or slabs. Fig. 26 is a plan of a wall built therewith, and Fig. 27 a perspective elevation of a wall in

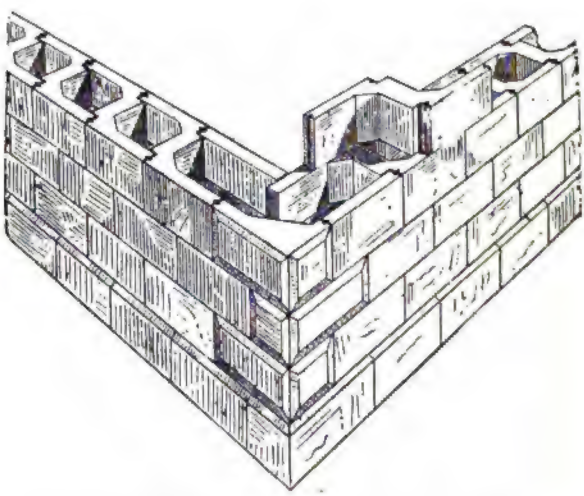


FIG. 27.—Perspective View of "Z Block" Building.

course of construction. The tail ends of the slabs, as will be seen, fit into the opposite or rebated ends. The angles of walls required special quoin slabs, and the ordinary

facing slabs bond or tied themselves together in an ingenious manner. An objection was that the cross tie portion cut or divided the concrete core, but the strength even then was far above that of an ordinary brick wall. The vertical joints come opposite to a solid, and this was an advantage; Mr Lish said that a strong wall could be constructed without any filling in or concrete core, but leaving the cavities hollow as shown. Messrs West & West, in 1874, and several others since then, have also from time to time introduced concrete facing slabs nearly all of a similar character to one or other of those just described, some of considerable merit, but not finding their way into general use, not even in neighbourhoods where concrete materials are abundant and bricks dear, although

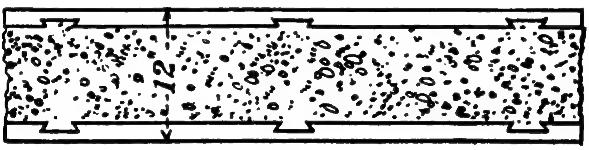


FIG. 28.—Drake's Slabs.

for special purposes they would be more advantageous than brick or stone.

Mr Drake devised a form of facing slab, having dovetail grooves on the inside face to form a key for the concrete core, but they were not successful from a commercial point of view.

I employed concrete facing slabs having dovetail lugs at each end for numerous buildings, and which were fairly successful. The late Mr Lascelles erected several buildings with them, but like others of a similar character they eventually fell out of use.

The usual method of casting concrete slabs is to use wood or iron moulds, or wood lined with zinc, iron being the most durable and best, but the cost is considerable, as the surfaces should be planed to render the slabs smooth

and true on the face, and to prevent the cement from adhering to the rough surface of the iron. A movable rim of wood to regulate the thickness of the slab is necessary, the surface being ruled off with a straight-edge, the face side being undermost. The process of making concrete slabs is a very simple one; the mould or pallet being laid on the bench, the surface is brushed over with linseed oil or any fatty oil, or half paraffin and oil, or soap dissolved into a thick lather; there are purposes, seemingly, for which each is more suitable than the other, and the better way is to try which, in practice, best prevents the

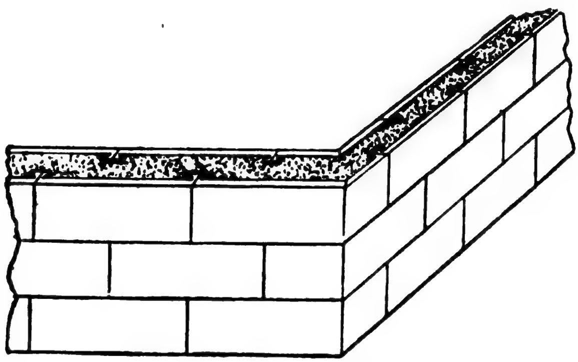


FIG. 29.—Potter's Slabs.

cement from adhering to the mould. Immediately after the mould has been brushed over with the oil, or solution, "slip," or neat cement mixed stiff, *i.e.*, cement to which no sand is added, is spread over that portion which is the counterpart of the visible portion of the slab when fixed, and as thinly and evenly as possible.

This forms the smooth surface of the slab, without which the face of the latter would be very rough and unsightly when withdrawn from the mould. The concrete is then deposited on the thin layer of cement, slightly beaten or pressed to drive out the air which permeates the material, and with a straight-edge levelled off fair with the

sides or edges of the mould. In twenty-four to forty-eight hours—depending upon the temperature and proportion of cement employed—the sides and ends of the moulds are liberated, the portion upon which the slab rests gently turned over, and the slab dropped out on to sand, or some soft material, to prevent it breaking. One part of cement to four parts of an aggregate is a fair proportion to use for concrete slabs, the unavoidable small size of the aggregate necessitating more cement than a coarser one would require. It is strictly necessary that the cement should be well seasoned; if the slab is not very thick, the use of fresh cement will cause it to buckle and become distorted in hardening. A coarse cement is also injurious, developing hair cracks on the surface. For the "slip," or cement facing, it is advantageous to use a finely ground cement, say what would pass a 76 lineal or 5,776 superficial mesh per square inch, and leave not more than 5 per cent. residue.

It often happens, even with iron moulds, that there is considerable difficulty in liberating the slabs, which fracture before they will come away therefrom, but the more the moulds are used the better the slabs leave them. As a matter of course there must be no undercut portions in the article to be cast; where these are essential then jelly moulds similar to those used by modellers and ornament makers are necessary.

The natural colour of Portland cement is sometimes considered an objection for wall slabs and other purposes, and this has led to the staining or dyeing of the slip with which the face of the mould is skimmed to form the smooth surface of the casting (see Chapter XVII.).

It has been attempted to face concrete slabs with glazed tiles, glass, and other washable substances, as was done in former times by the Romans and others; in smoky towns this would be an important factor in promoting sanitation, and no inconsiderable aid to cleanliness, but it does not appear to have become a success as yet, although there cannot be any insuperable difficulties in the way. Mr

Michael Henry, in 1863, used powdered marble, glass, granite, flint, and mineral colours for facing concrete, afterwards polishing the surface ; the late Mr Lascelles, of Bunhill Row, took out a patent with this object in 1887 ; Mr Charles Drake also some years after patented the same process.

Another system for using concrete for walls is as a filling in, or core, facing the wall on the outside only, or on both sides. If faced on the outer side with bricks, stone, or other materials, a temporary wood casing is required inside for retaining the concrete in a soft state until set. Practically this is more troublesome and quite as costly a process as forming a trough for an entire concrete wall, and has therefore not come into general use. Facing the wall on both sides and using concrete as a core, can, obviously, be adopted only where the walls are of a substantial character, say not less than 18 inches in thickness. The thick walls of the Romans gave every opportunity for using concrete in this way, and which such skilful builders were not slow to avail themselves of.

But we have few instances comparatively speaking, in modern times, of the walls of buildings of any magnitude built with a concrete core. The late Mr W. White, F.S.A., erected a church—St Mark's, Battersea Rise—in this way in 1874, the casing of the walls on both sides being brickwork 4½ inches thick, *i.e.*, the bricks were laid longitudinally as Flemish bond, so as to provide a thick core of concrete, and economise their consumption. But every tenth course was a through course, *i.e.*, a layer of bricks over the entire area of the walls, to create bond or tie, and every intermediate or fifth course was a header course with the same object.

This arrangement broke up the monolithic character of the wall into blocks of concrete 2½ feet in depth, while the header courses being opposite each other, divided the solid wall at those points by brickwork 18 inches thick. As however the walls were 3 feet thick, there was ample

strength left in the 18 inches of Portland cement core that remained. The concrete was composed of one part of Portland cement to six parts of an aggregate, and the bricks were bedded in cement. A difficulty presented itself at the commencement, inasmuch as the casing bulged outward from the pressure of concrete; this was at first remedied by battering the walls inward, and allowing the concrete to force the facings to a perpendicular line. This is not a practice to be recommended—the result might not always be satisfactory. But it was thought that possibly the cement expanded through being new, and it was therefore spread out on a wood floor and allowed to cool; it was then found that the walls underwent no perceptible change of form. The result, so far as the strength of the walls was concerned, was satisfactory, but the cost was found to be more than if built with all bricks laid in mortar.

The illustration (Fig. 30) shows a church erected in a similar way in Hampshire in 1890. The facings used were Chilmark stone dressings and hammered flints on the outside, and Caen stone on the inside. The core was composed of Portland cement concrete in the proportion of one to seven. The aggregate was obtained from the walls of the old church and other buildings adjacent to the site of the new church, and about 1,000 cubic yards altogether of concrete were used. The aggregate was reduced to a suitable consistency by means of a Blake crusher. As the aggregate was principally obtained within 200 yards of the site, and as on the other hand, if bricks had been used, they would have had to be carted 5 miles from the nearest railway station, and brought 20 miles by rail, the saving in haulage alone was a large item.

The flints, which were faced and randomed coursed, were built in cement, and about 12 inches in height at a time; the Caen stone facing, which was purposely of irregular thickness ranging from 2 to 4 inches, was bedded as near the same height as the courses permitted, and a few hours at least and a day when practicable given the cement

mortar to harden before the cement concrete was deposited in the cavity. No difficulty was experienced in keeping the wall facings perpendicular, the cement being kept a month before use, and no bond was needed beyond that afforded by the irregular size and shape of the flints, and the steps formed by the different thicknesses of Caen stone facings. The cost of the concrete in walls was considerably less than if bricks had been used, while the strength of

FIG. 30.—A Faced Concrete Church.

the walls—some portions being 4 feet in thickness—may perhaps in the far future afford Macaulay's New Zealander —if he travels that way—an opportunity of remarking that there were at least some buildings in the nineteenth century erected with a view to durability. The tower and pulpit stairs are concrete throughout.

The flint panels, seen in the apse and tower walls, &c., are of novel construction; wood moulds were made of the

necessary shape, the flints were placed therein face downwards, and the moulds filled up with concrete, the total thickness being about 4 inches. Many of these panels were 5 feet in height, and weighed 2 cwt. each, but no difficulty was found in making or fixing them; the latter was executed by masons. No flint facing, formed by bedding a flint at a time, could possibly equal the remarkably regular and smooth appearance of this portion of the flintwork when seen in juxtaposition with the ordinary flint walling.

The churchyard boundary wall copings are of flint, cast in moulds, in lengths of 4 to 5 feet, and bedded and jointed in the usual way. The cost was much less than any other durable kind of coping, except common bricks. The tracery panels of churchyard walls, as seen in the illustration, are of red concrete, made on the site from the masons' chippings and other débris.

This church was built in 1889-90, and is a good example of the use of concrete in a way that no possible objection can be taken to. The whole of the concrete work was executed, with the exception of the tracery, flint panels, and wall copings, by rural labourers.

There is yet another system of using concrete for walls, although buildings erected in this way can scarcely be designated "concrete"; viz., by casting the concrete in slabs, and screwing them to a wood framing. The late Mr Lascelles introduced this system, and cast the concrete to represent tiles, each slab being from 2 to 3 feet square. Houses made therewith are no doubt dry and warm, and their appearance is all that could be desired, but the principle scarcely commends itself as one for general adoption.

The main difficulty in connection with the manufacture of concrete slabs is the time which must necessarily intervene before the slabs can be released, and the moulds are free for re-use. In an ordinary way two or three days is necessary, and even more in cold weather unless the

moulds are kept in a warm building. The use of fresh cement, which sets quicker than stale, hastens the set of concrete, but as before explained will cause the concrete to buckle as it becomes hard. Hot water for mixing the concrete will effect the same object, but occasionally with a similar result.

It has been attempted to introduce silicates of various kinds in a bath of water, and immerse the slabs therein, with the object of setting up a chemical action and thereby causing the cement to set quicker, but it is doubtful if any process of this kind is of much service. Mr Buckwell, who used concrete at the building of the Crystal Palace at Sydenham in 1860, employed silicate of potash as a coating—or, where practicable a bath in which the silicate was mixed, and when the concrete was nearly dry painting it with chloride of calcium. Mr Kirrage, in 1865, employed burnt clay or any materials containing silica mixed with Portland cement, to hasten the setting and increase the hardness; he also used sulphate of iron, one part to ten parts of Portland cement, and sometimes ½ oz. of common crystals of sulphate to every gallon of water used for mixing the cement or concrete.

Silicate of soda is the material now used, and the proportion to be employed depends in a measure upon the size of the slabs or other concrete articles to be deposited therein. Mr Faija said he found that with ordinary cement a saturated solution of soda or potassa diluted with five or six times its bulk of water will cause concrete to set quickly. The general opinion, however, appears to be that in the majority of cases slabs or concrete of any kind immersed in a bath containing silicates are hardened only a little way beneath the surface, unless kept in the bath for some considerable time, and one of the main objects of employing silicate baths—the saving of time—is in this way rendered nugatory.

To remedy this, Mr Faija, in 1881, subjected the concrete to a moist heat shortly after it was mixed; he pro-

posed to heat a chamber by hot water or steam pipes to a temperature of about 100 degrees Fahr.—or by any means whereby a moist but not a dry heat could be produced. The concrete slabs, or other concrete manufactures, having been put into the mould in this heated chamber were left until hard enough to remove, when they were taken out of the mould and put into a warm bath composed of one part of silicate of soda, or silicate of potassa, to five or six parts by measure of water. The temperature of the bath to be from 70 degrees to 75 degrees, but 95 degrees to 120 degrees, Mr Faija said was most suitable. Mr Hodson at a later date appears to have adopted the same process, and Mr Highton of Brighton, so long ago as 1868, patented a process for treating surfaces of concrete with a paint consisting of soluble silica or prepared silicate of iron, lead, copper or zinc, mixed with the ordinary ingredients for common paint.

But any process which adds cost to the manufacture of concrete slabs, blocks, or other articles, and with but doubtful results, is not likely to receive very much attention. If concrete could be made to rapidly harden at a small cost, and without any injurious results, it would help the use of concrete slabs and blocks for building purposes, but as yet neither has secured a very large amount of favour.

In slabs, or any description of cast work, small portions of air get confined in the mass, and which if not liberated form minute cavities; if these are numerous they weaken the castings and are best got rid of by shaking them while the concrete is soft. Where the manufacture of slabs, paving and the like is made a special business, a machine called a trembler is used for the purpose.

CHAPTER X.

HISTORY OF FIRE-RESISTING AND CONCRETE FLOORS.

SUSPENDED floors, in contradistinction to floors bearing upon the ground, have always been an element of danger. Up to comparatively modern times wood has been almost the only material available, and wood floors placed one above the other at intervals of a few feet have been the main contributory cause of most of the large conflagrations. This knowledge has been the means of attempting in various ways for centuries past to devise some means either of rendering wood incombustible or of adopting incombustible materials in its place, but until the introduction of rolled iron and steel and Portland cement, the latter was impracticable in an ordinary way. When oak was in common use for building purposes there was very much less danger from fire than when the resinous woods from Norway and Sweden took its place.

Brick arching to form cellars and strong rooms beneath the ground floor was a common practice in olden times, the walking surface of the floor itself being stone slabs, tiles, or less often boards nailed to light joists.

Although the Romans, and subsequently the Normans occasionally adopted concrete floors, for which lime was the matrice, they do not appear to have used them to any great extent, nor was there the same necessity when wood was more sparingly used than at present. The House of the Vestals in ancient Rome, however, was said to have had concrete floors of 20 feet span and 14 inches in thickness, with no intermediate supports.

The earliest record of a patent for fireproofing buildings in this country is that of Dekins Bull, and dated 1633; at that period it was unnecessary to publish what a patent comprised, but simply to state that the inventor possessed a secret for some special object, and to petition that he alone, or others whom he might appoint, should be allowed to practise it. Dekins Bull's declaration is somewhat amusing. It runs thus:—

"Charles by the grace of God, King of England, Scotland, France, and Ireland, Defender of the faith, &c.; to all to whom theise psent shall come, greeting.

"Whereas Dekins Bull, by his humble peticon vnto us exhibited, hath shewed vnto vs that wee, for the beautifying of the Cittie of London, and the subvrbs thereof, have enioyned all buildings to bee made of bricke; and the said Dekins, by his painefull endeavour and studdy, hath founde out a seacrett mistery for the '*Making Staunch all* Manner of Plattformes, Tarises, or any other Roomes belonging to Architecture, soe that neyther Fire or Water shall never Endanger or Hurte any House or Houses being Finished with his Worke'; and he will doe the same with very little more charge than now the builder is att, and will approve itt to be for strength, pleasure, health, and proffit of the subiect as well as his safety from casualty of fire and water, and hath humbly besought vs to bee graciously pleased to graunte vnto him our Lres Patent for one and twenty yeares, that none but hee or his deputies may vse or practise his said Invencon in this our Kingdome of Englande."

Dekins Bull did not, however, obtain all he asked for, as his request for twenty-one years' protection was cut down by the Privy Council to fourteen.

It is quite possible that the patent was for some method of rendering wood fire resisting, and not for any system of construction.

The Great Fire of London in 1666 should have brought Dekins Bull's and other inventions for fire resistance to the front, but there appears to be no record of any having been

adopted. A pamphlet was published in 1785, written by Mr Hartley, member of Parliament for Hull, and called "An Account of the Invention and Use of Fireplates for the Security of Buildings and Ships against Fire." The process consisted of covering all exposed timbers with thin iron plates or sheet iron, and occasionally dry sand or rubbish between, and was applicable principally to wood beams, floor joists, ceiling joists, and rafters. An experimental house was built of wood, and a report at that time stated that although faggots and pitch and tar were placed in each room the wood was uninjured. This arose from the same cause that wood nailed to concrete floors don't burn, but smoulders or chars when a fire takes place through the exclusion of air. Anyway the use of Mr Hartley's patent must have been a costly affair, but that it caught on is evident from the fact that a sum of £2,500 was voted Mr Hartley by Parliament, his patent was extended for thirty years, and an obelisk was erected on Putney Heath in 1776 by the Corporation of London to celebrate an invention of such national importance. The obelisk would have been an interesting object at the present time, but there does not appear to exist any record as to when it was removed. A few years later Lord Mahon—afterward Earl Stanhope—invented a system which was popular for a time of filling in the space between the wood joists with rough mortar laid on wood laths, what we now call "pugging," but the mortar was used much thicker and more carefully prepared than at present. Nothing further in the direction of rendering floors fire resisting appears to have been made public until the introduction of cast-iron beams. Mr Fairbairn, in his work "On the Application of Cast and Wrought Iron to Building Purposes," says "the first application of cast iron for forming floors was for a mill erected for Messrs Phillips & Lee, of Manchester, in 1801, and it reflects great credit on the skill of the designer." The beams were of this section ⊥, and had cast-iron columns as supports, and segmental brick arches springing from beam to beam.

No protection was given to the beams or columns, so that had a fire taken place the floors would probably have collapsed.

Mr Hodgkinson, an engineer, made a series of experiments in the years 1827-30, to ascertain the best section of cast-iron beams for sustaining heavy loads, and found that those with wide bottom flanges and narrower top flanges gave the best results, the weight of metal taken into consideration.

But years previous to this—1817—Mr Pritchett, at that time a well-known architect of York, adopted cast-iron beams and flat brick arches or slabs for the Wakefield lunatic asylum, but the floors were heavy as the bricks were solid, and by an Act of Parliament in existence at that time the bricks had to be of a certain size. At a later

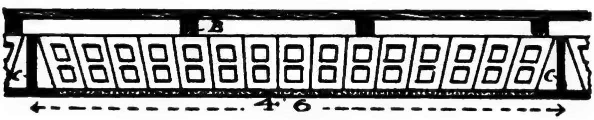


FIG. 31.—Pritchett's Floor.

period the Act was repealed, and hollow bricks were used by Mr Pritchett for the Retreat lunatic asylum at York. The beams as shown had no top flanges, and were fixed 4½ to 5 feet apart. Tie rods were used temporarily to keep the beams in place until the cement or mortar became hard. The camber, or rise of the arches, was about half an inch, and the ceiling mortar had therefore to be an extra thickness in the centre of each bay. B is a wood fillet for nailing floor boards thereto, and C fire-clay skew-backs. This may have been the first use of hollow bricks; the form of arch is almost identical with others of terra-cotta and brick patented systems of floor construction that have for years past been in use in America, and to some extent in this country. Some of Mr Pritchett's floors measured 25 by 20 feet clear of the walls.

Semi-fire-resisting floors have been known in Nottinghamshire and adjoining counties for hundreds of years past, and as their use is now practically abandoned, it may be interesting to give a description of the way they were constructed. Ordinary wood joists were used, and upon these were laid reeds or plastering laths, and over the latter a thin spread of straw to keep the liquid plaster from running through. The coarsest and roughest plaster made from the gypsum stone was spread thereon 2 inches in thickness or more, and when hard the surface either polished with a flat stone or smoothed with steel trowels. A coat of linseed oil or bullock's blood was given them when dry, which was supposed to harden the plaster, and the margins were occasionally painted to form a border. On two sides of the rooms—and if the latter were large, on all four sides—fillets of wood were laid against the walls before the floor was commenced, and withdrawn soon after it was completed, to allow space for expansion. The joists were usually planed and painted, and the ceiling between them formed by plastering on the reeds or laths.

Floors of plaster mixed with coal ashes were in general use in London a hundred and fifty years ago, and probably much longer. Some of the floors of Hampton Court Palace were constructed in this way with a layer of cockle shells embedded therein to prevent sound from passing through. As this class of floors was supported on wood joists there was very little resistance to fire, but they were a step in the right direction. About 1820, Mons. Lecomte, a Frenchman, anticipated numerous inventions connected with the use of fire-resisting floors and ferro-concrete; among others, circular sheet-iron flue pipes for embedding in concrete to form smoke flues, wood beams with iron flitch plates for carrying loads, iron plates for concrete floors with iron rods passing through in a transverse direction, and metallic network for ceilings in place of wood laths. Mons. Lecomte—like many other inventors—was before his time, for it was many years after before his inventions were adopted.

James Frost patented "a new method of casting or constructing floors and ceilings," &c., in 1822, and the mode of procedure he describes as follows: "Ceilings, whether arched or otherwise, are divided into compartments by iron ribs, these being furnished at the lower parts with small rims or mouldings to receive and support such compartments, and the moulds must be surcased inside before use with some substance which will prevent adhesion thereto of the materials employed for the work, the moulds being of course removed as the materials harden.

"The moulds are fixed by means of supports or braces

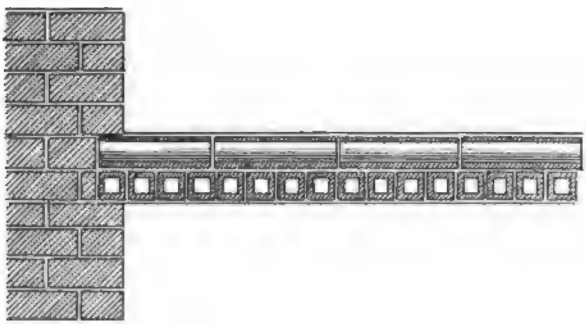


FIG. 32.—Frost's Floor.

in the situation of the structure required, so as to bound exactly the surface of the intended work. The complete structure may then be formed by using a quick-setting calcareous cement, having hard and durable substances embedded therein, as for example Roman cement mixed with bricks, tiles, stones, gravel or shingle."

Mr Frost, who established the first manufactory for making cement on the Thames, introduced a fireproof floor (Fig. 32) about 1840, formed in the following manner: earthenware tubes 2½ inches square externally were made by a machine, in 10-feet lengths, and previous to being burned were cut to 1-foot lengths. A centering or platform was formed, upon which two courses of these tubes

were laid at right angles to each other, embedded together with neat cement. The surface was finished with cement or tiles. This arrangement was said to be sufficiently strong for any ordinary load up to 10 feet between supports.

Here we have a hollow tile floor only 5 inches thick, and which, apparently *pro rata* to its thickness, was equal in strength to the hollow tile reinforced floors in use at the present time.

Probably Frost derived his idea for this kind of floor from a custom at one time of forming coverings to areas and forecourts by bedding three courses of plain roofing tiles together with cement, breaking joint as a matter of course, spans up to 8 or 9 feet being usual. Louden in his "Encyclopædia of Cottage and Villa Architecture," published nearly seventy years since, recommends this arrangement for floors and roofs. Mr Louden also wrote: "Floors and roofs might be made flat by means of a lattice work of iron tie rods, thickly embedded in cement or concrete and cased with flat tiles"—another anticipation of reinforced concrete.

In 1840 there was a strike of carpenters in Paris, resulting in, if not the introduction of concrete for floors in modern times, certainly their extended use in Paris. The proximity of the gypsum quarries, the stone from which plaster of Paris is made, helped in this direction, as it could be purchased at a low cost. Possibly Lecomte's system was adopted in some instances, but the ferro-concrete systems which became more general were those of Vaux and Thusane. In the former the principal supports were plates of wrought iron fixed edgewise at certain distances apart, and of varying depths according to the span, and having square iron bars bent to clip the plates and suspended therefrom. Lighter rods or wires were occasionally attached to the iron bars, crossing them so as to form meshes of any size required. The ends of the plates were sometimes split and turned sideways to grip or tie them to the walls. A temporary wood platform was fixed nearly

close to the plates, and their full depth or more filled in with *beton*, the French name for concrete, the aggregate being put in dry and the liquid plaster poured over it;

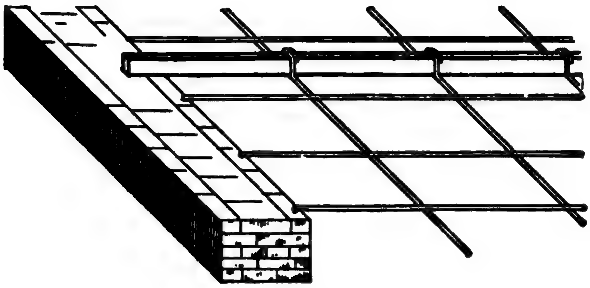


FIG. 33.—Vaux's Floor.

what we should call "grouted." As plaster sets very rapidly, the ordinary way of making concrete, as we understand it, was not practicable.

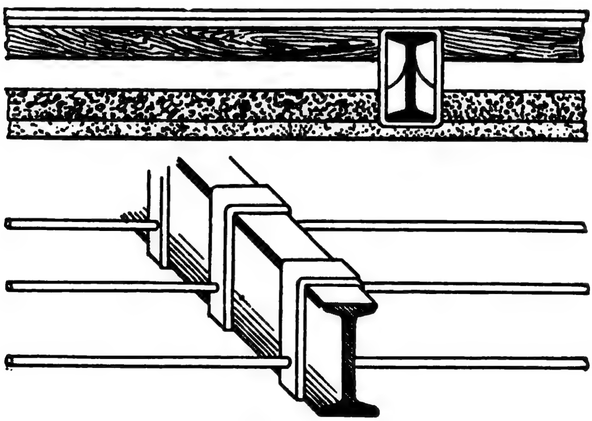


FIG. 34.—Thusane's Floor.

In the Thusane system, wrought-iron plates and eventually rolled-iron joists were used instead of plates, but the system was very similar to the Vaux, except that

the fireproofing was simply a concrete ceiling, ordinary wood joists in the usual way being used and floor boards nailed thereto. It will be noticed that Thusane's system with iron clips, having mortices therein to uphold iron bars or rods, is similar to the present Columbian floor, except that in the latter rolled joists take the place of bars, rolled joists not being available in Thusane's time.

In Paris, reinforcement by means of flat bars on edge, rods with their ends turned down to get a grip of the concrete, and other devices, the iron being embedded in the concrete, was gradually introduced and soon became well known and in common use. The rods and bars were usually fixed near the ceiling level to resist tension, and vertical members were attached thereto and to corresponding rods or bars near the floor level to resist shearing stress, a principle similar to systems in use in this and other countries at the present time, and claimed as modern discoveries.

As a matter of fact most systems of concrete construction for foundations, walls, floors, and generally, are identical with or grounded on similar methods practised—some—many centuries ago, but which the cycle of invention rejuvenates at intervals. The American form of hollow terra block, or burnt clay slab construction, and the many variations of the same are possibly taken from the ancient method of forming floors in Italy, or of quite a similar character adopted in Paris over sixty years ago. The latter form of floor is illustrated in Fairbairn's "Engineering" published in 1870.

The first concrete floor in which the common form of rolled-iron joist was used as a support for the concrete was for a house No. 18 Boulevard Filles du Calvaire, Paris, the span being 18 feet. At that time rolled-iron joists were scarcely known in this country.

Another system which was in use in Paris at the same period was to employ circular earthenware tubes or pots about 7 inches in length, made slightly taper to form a key

for the concrete, and one end closed; these were stood on end and close together, and the spaces between filled up with fine concrete or liquid grout.

Here, however, the Romans had forestalled the Parisians, for remains of pottery floors are to be found in the ruins of some of their old buildings. The dome of the round church of Ravenna is constructed in a similar way. About 1789 the Academy of Science of France instituted a series of experiments with a view of determining the amount of thrust, or force of resistance of cambered floors of this character.

Mr Loat, a builder of Clapham, obtained a patent in 1843 for forming floors with hollow earthenware pots. Loat, in his specification, acknowledges the use of hollow

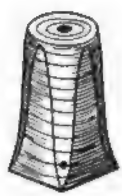


FIG. 35.—Pots for Floors.

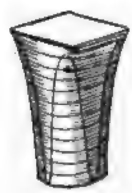


FIG. 36.—Loat's Pot.

pots to be a well-known arrangement, but claims that floors so constructed had up to that time been arch formed, and that tie rods were indispensable, but that by his plan floors and roofs could be made quite flat, and the use of rods discarded. A temporary platform had to be constructed on which the pots were laid and cemented together, and when the latter were sufficiently rigid the platform was removed. These pots were 4 to 6 inches deep and of various shapes—cylindrical, polygonal, &c. The floor surface was laid with paving tiles, and the ceiling beneath formed with iron laths, the ends of which were turned up and built into the joints of the pots as the latter were fixed, an arrangement suggestive of some considerable difficulty.

Hollow pot floors found great favour in Paris for a long

time; some in the palaces of Versailles and the Tuileries are 66 feet in length and 33 feet in width.

The French systems of ferro-concrete floor construction, *i.e.*, of using iron embedded in the concrete, were the first of the kind in modern times, so far as I am aware; possibly iron to strengthen plaster concrete floors may have been used in Italy previous thereto, for plaster floors appear to have been common there for centuries, and mostly executed somewhat similar to those in Nottinghamshire and Derbyshire.

Another system common in Italy in former times of forming fire-resisting floors was to first leave chases or indents on the inside of all walls upon which the floor was to have a bearing, to receive a first course of tiles about 12 inches in length, 2 to 3 in width, and 1½ in thickness, and laid flat; another course was cemented to this, and so on until the floor space was filled in. The floor was slightly arched; a scaffold was fixed below for men to walk on, and strong enough to enable slight wood props to rest thereon, and uphold the tiles temporarily until the plaster of Paris—which was the cementing medium—had got hard. The hollows or spandrels of the upper side of the arch were filled with sand or gravel, and finished with a plaster or tile surface.

At this point I would remark that when iron or steel, in combination with concrete, came into more general use, it was found necessary to give the combination a distinctive name, and "armoured concrete" was the result. But the appellation was misleading; people were led to suppose—until they were told different—that armoured concrete was concrete encased in some way to afford protection analogous to the armour plating of vessels, whereas armouring of concrete was for strengthening it, not for external protection. So the name was abandoned and "reinforced concrete" substituted, and which better indicates its meaning.

The *Builder* suggested "concrete steel" as a suitable

title, but this too was scarcely suggestive enough for the general public. The latest prefix "ferro" has been adopted in some cases in this country, and will remain possibly until some more significant term can be found.

"Ferro" is the chemical word for anything appertaining to iron, and is derived from the Latin word *ferrum*,

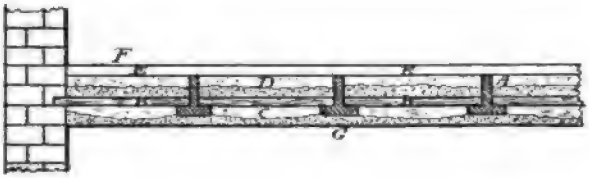


FIG. 37.—Fox and Barret's Floor.

iron. Although the meaning of the prefix "ferro" is not very clear, it is of little consequence, so that the meaning is recognised, *i.e.*, that ferro-concrete is concrete in which steel or iron is embedded—no matter in what form or how disposed.

The first system of fire-resisting floor construction in

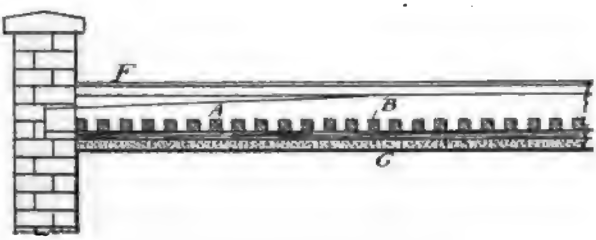


FIG. 38.—Fox and Barret's Floor.

this country that came to stay was Fox and Barret's. Mr Fox was a doctor living at Northwoods in Gloucestershire, and obtained a patent in 1844 for an "improved method of constructing fire-proof floors, ceilings, and roofs." But it appears Dr Fox had applied his system fifteen years previous in the construction of a large lunatic asylum at Bristol.

Fig. 37 is a section of Dr Fox's floor, and Fig. 38 a

transverse section of the same. Small cast-iron girders, A, of a ⊥ shape, deeper in the middle than at the ends, were fixed 18 inches apart, and bedded on the walls at both ends. In the spaces between the joists and resting on the bottom flanges of the girder were placed strips of wood, B, about $1\frac{1}{2}$ inches square and $\frac{1}{2}$ inch apart. A coat of rough rendering mortar about $\frac{3}{4}$ inch thick, G, was spread over these laths, and as it squeezed through the interstices it formed a key for ordinary plastering mortar for the ceiling of the room beneath. Upon this rendering coat, coarse mortar on concrete pugging, D, was laid, made of road sand, coal ashes, and lime, and lastly upon the pugging a layer of lime mortar, E, formed of two parts of coarse sand and one part of lime trowelled off quite smooth. The surface, F, was afterwards saturated with linseed oil, made hot, with a view to harden it, and Dr Fox stated that "this makes the floor so hard and tough that it is not liable afterwards to be injured by the brushing, cleaning, or moving of furniture to which it may be subjected."

Precise data for the construction of a floor of this kind at Northwoods will give an idea of the system of construction:—Bearing between walls 18 feet, cast-iron joists 3 inches deep at each end, tapering to $5\frac{1}{2}$ inches in the centre; thickness of iron as follows:—Webs of girders, $\frac{3}{4}$ inch at bottom tapering to $\frac{5}{8}$ inch at top; bottom flanges, $2\frac{1}{2}$ inches wide and $\frac{7}{8}$ inch thick, including the depth of the web; weight of iron, $15\frac{1}{2}$ lbs. per foot lineal; distance apart of bottom flanges, 18 inches. It will be observed that Fox and Barret's floor was not so deep as many wood floors require to be. It was some years before any improved fire-resisting floor superseded Fox and Barret's, and sixteen years after it was patented (1864) it was in common use.

The floors of the L.B. & S.C. railway station at London Bridge, Balmoral, and many other buildings in London and elsewhere are formed on Fox and Barret's principle.

When rolled-iron joists came into use cast iron was abandoned.

Between the years 1840-50 the fire-proofing of buildings, owing to several large conflagrations, received more attention, and papers were read before the R.I.B.A. and the Institute of Civil Engineers relative thereto. At one of these the Chief of the London Fire Brigade—Mr Braidwood—recommended stone and iron for stairs. The exhaustive series of experiments made by Mr Stephenson in 1845 and following years in connection with the building of the tubular bridge across the Menai Straits were the primary means of introducing wrought-iron girders, resulting in the use of cast iron being abandoned for ordinary floor construction. That iron was gradually coming into use in place of timber beams at that period is clear; Gwilt, in his "Encyclopædia" published in 1842, says: "The security afforded not only for supporting weight, but against fire, has of late years very much increased the use of iron, and may in some cases entirely supersede that of timber." Mr Wild, an engineer, in 1842 patented the use of a peculiar form of brick floor on cast-iron girders, the brickwork graduating or stepping at the springing, until it was only about one-third as thick midway between the girders as at the bearings on the latter. In 1845, Lieutenant Higginson obtained a patent for floor construction, using T cast or wrought iron girders ingeniously dovetailed together, but the inventor getting into difficulties, the patent remained in abeyance until further improvements in the same direction took place. The failures that had occurred in the manufacturing districts of cast-iron girders for floors, and the experiments going on to test the best kind and form of iron girder to carry heavy loads in connection with the Menai Straits Bridge, led Mr Fairbairn, in conjunction with Mr Hodgkinson, in 1845, to take up the subject and to patent a wrought-iron beam formed of two webs or flitch plates connected to upper and lower flanges by angle plates, the tendency of the webs to bulge being counteracted by

transverse pieces of tubing in the centre of and between the webs, through which bolts were passed and riveted. This was the original form of built-up or box-girder, where heavy weights had to be supported.

Messrs Fairbairn's and Hodgkinson's experiments were the forerunner of probably the earliest wrought-iron girder and concrete floor, invented by Mr Beardmore, an engineer, in 1848. The beams or girders were formed with angle plates riveted to the top and bottom of the web, and after the girders were fixed in place, iron plates were sometimes riveted to the bottom flanges to carry the concrete, and if the floor was required to be very light, or the girders were deeper than usual, common earthenware tubes were embedded in the concrete, as shown by Fig. 39.

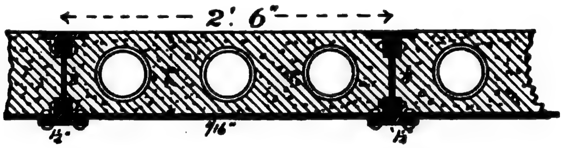


FIG. 39.—Beardmore's Floor.

It was assumed that the water contained in the concrete would cause serious corrosion of the iron it encased, and to avoid this the girders were to be either galvanised or painted. It is common knowledge now that Portland cement concrete prevents, instead of induces corrosion. For the experiments made in testing Beardmore's floor, concrete was used composed of White's Portland cement—at that time just becoming known—and shingle, in proportions varying from one to six to one to nine. The iron was considerably exposed in case of fire, but the inventor claimed "absolute fireproof qualities" for his invention, and moreover lays particular stress on "the non-liability of concrete to disintegrate when exposed to fierce flame, as brick arches are known to do—in flakes." At that period iron and stone were considered *par excel-*

lence the best possible materials to resist a fierce fire. Mr Fairbairn in his work previously mentioned, says, " the first condition in constructing fireproof buildings is, that the whole of the building be composed of incombustible materials like iron, stone, or brick, and that an isolated stone or iron staircase be attached to every story of a building," an opinion, so far as iron and stone are concerned, at variance with experience gained from large conflagrations at a later date.

In the same year (1848) Mr Naysmith, an engineer, of Ebury Street, Pimlico, invented a plan for making concrete floors, Fig. 40, the forerunner of improved systems of a similar character in use at the present time.

Mr Naysmith employed plates of thin iron, bent so as

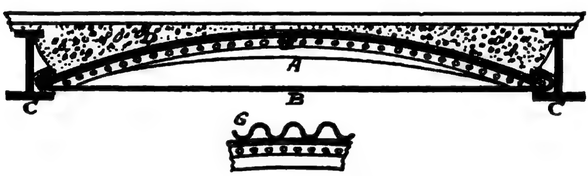


FIG. 40.—Naysmith's Floor.

to form a segment of a circle. The iron plates rested on light arched ribs, A, with an angle iron stiffener, E, riveted to them as shown. The main feature of the invention was the chord bar or tension rod B; D is cement concrete filling-in, and C cast-iron girders fixed at intervals as found necessary. Corrugated iron was specified to be used instead of flat iron plates if occasion required as G, and there were other adaptations and variations named in the patent. The patentee proposed Portland cement concrete for filling-in, and tiles or wood for the floor surface. The concrete spandrels were to have cavities or hollows cast therein to facilitate warming and ventilation, or reduce the dead weight if necessary.

Wilkinson, of Newcastle, in 1854, describes in his patent the use of wire rope, or other form of iron in a state of

tension, being embedded in the concrete, and the drawings show how the rods, ropes, or bars should be twisted or looped at the ends to prevent sliding when the floor was under stress. Mr Wilkinson proposed to fix his wire ropes about 9 inches apart, and the thickness of the floor to be one-sixteenth the span, so that a floor 16 feet in width would be 1 foot thick. The proportions were to be one part of Portland cement—or other cement of equal quality—to five parts of crushed bricks, metallic scoria, broken stone, or other hard substances.

We have here a ferro-concrete floor designed on correct principles, if rudimentary in character.

M. François Coignet, a Frenchman, patented a system of making concrete, or *beton*, from hydraulic lime in 1855. In 1861 M. Coignet published a pamphlet advocating metal reinforcement, and described various ways of applying it for strengthening concrete floors, &c.; but although his system appears to have received some attention in France it was not until 1879 that any work was carried out by him in this country.

The much earlier systems of Lecomte, Thusane and others, of using rods and bars embedded in concrete probably had something to do with this invention.

Mr Dennett, a builder of Nottingham, introduced so-called fireproof floors in 1857, and, with many improvements since then the Dennett floor is still in use. At that period, wood, in conjunction with iron, was not considered an objection for fire-resisting floors in many buildings. Dennett's floor was made of plaster of Paris, or gypsum, mixed with broken bricks, cinders, and similar substances, and was in fact simply a concrete arch with plaster as a matrice. But in 1863 Dennett filed a new specification for floors of a somewhat improved character. Fig. 41 shows one of these floors, and ceiling of apartment beneath, supported by corbels at each end and a wood beam in the centre, and described to be suitable for cottages, and Fig. 42 is a similar floor with a wrought or cast iron beam taking the place of

wood. Wood ceiling joists were added if a flat ceiling was required, but without these the inventor stated that his floor and ceiling were 20 per cent. cheaper than those of ordinary construction, and that spans of 17 feet clear of supports were quite practicable.

Mr Bunnett, of revolving shutter fame, patented, in the year 1858, quite a different class of fireproof floor, viz., of

FIG. 41.—Dennett's Floor.

hollow interlocking bricks or blocks, made so as to joggle or key each other, a principle since adopted in an almost endless variety in America. If not forced apart it would appear almost impossible for such a floor to fall; this was provided for by means of iron screw tie rods passing through angle-iron wall plates, and with heads and nuts at end as shown. Fig. 43 is a section of Bunnett's floor; A is a section,

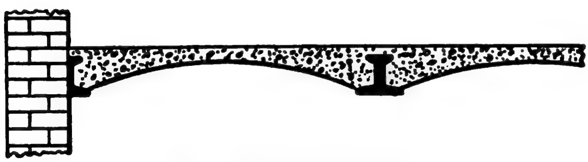


FIG. 42.—Dennett's Floor.

and B a cross section of blocks, which were, however, varied in shape according to circumstances. By preference the rods passed through the hollows in the blocks. The latter were channelled or joggled both at sides and ends, so that perfect interlocking was practicable. The weight of Bunnett's floor was given at about 240 lbs. per superficial yard, and with a bearing of 15 feet between supports withstood a distributed

load of 267 lbs. per superficial foot, with a deflection of $\frac{9}{81}$ of an inch, and without breaking down. A camber, or curve, of 2 inches in 10 feet was, as a rule, adopted, and the top was levelled up with concrete or tiles, or joists were laid on the blocks and flooring fixed thereto according to requirements. Dovetail grooves were also made in the blocks to form a key for the plastering of the ceiling. This form of floor was adopted for the Grosvenor Hotel, Victoria Station, London, and many other buildings.

About 1860 Mr Brannon, an architect and engineer, anticipated the use of wirework and iron in other forms, as

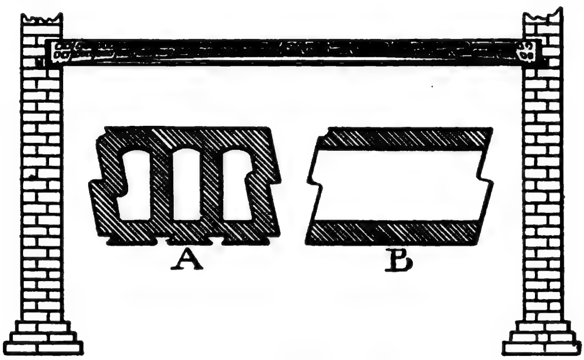


FIG. 43.—Bunnett's Floor.

reinforcement, for he describes his invention as—"A mode of forming roofs, floors, ceilings, doors, walls and other parts of buildings or other structures of cement or concreted materials in combination with metallic, fibrous, or laminated substances, with a view to render them more durable, fireproof, and healthy, and consists in employing for the said purposes a sustaining metallic framework or skeleton firmly fixed and bolted or bound together, and upon which is stretched wirework, so as to partially enclose or be completely embedded in the said concreted materials which compose the body of a structure, or any part thereof, and thereby perfectly bonding the same into a solid and coherent mass."

The system was, however, too costly and intricate to come into general use.

In 1862 Mr Matthew Allen, a builder, constructed the floors of the Waterlow Model Buildings in Finsbury of ferro-concrete. He used iron bars on edge, 3 inches by ½ inch, stretched across the building, similar to Vaux's, but 2 feet apart and built into the walls at each end, and crossing them with ½-inch iron rods also 2 feet apart, so that a 2-feet mesh was in this way formed. A temporary platform being fixed under and close up to the bars, concrete was deposited thereon 4 inches or more in thickness, according to the span, and light joists or strips of wood being laid on the concrete a boarded surface in the ordinary way was available. It is quite evident that Mr Allen had become acquainted with the French system of floor construction.

Mr Cheyne, about 1863, patented a fireproof floor similar in most ways to Fox and Barret's, but the inventor used corrugated iron sheets bolted to the bottom flange of the iron girders, in place of wood strips; the system does not appear to have become popular.

Mr H. M. Eyton, an architect, in a communication to the Society of Arts in 1864, gives the following table as representing the comparative cost of various kinds of flooring at that time, for a span of 14 feet clear between walls, but as at the present time, and as with all kinds of floors, the greater the span the more costly in proportion they become:—

Per 100 Superficial Feet.	Thickness of floors in inches.	Cost. £	s.	d.
Wood joists, inch boards, and lath and plaster - - - - -	11	4	8	6
Same if pugged - - - - -	—	5	8	6
Brick arch, 4½ inches thick, iron girder, use of centering, and levelled up for tiles - - - - - -	13 and 20*	4	15	0
Same if boarded and the underside levelled and lath plastered - -	24	7	0	0

* Thickness at springing and at haunches, and at crown.

Per 100 Superficial Feet.	Thickness of floors in inches.	Cost. £ s. d.
Hollow brick arches, cost depends upon the price of bricks, which would have to be specially made.		
Fox and Barret's with a cement surface	9	5 18 0
Same if boarded	11	7 3 0
Beardmore's boarded surface	11	8 5 0
French systems about the same as Fox and Barret's.		
Dennett arch	13 and 3*	3 10 0
If tiled	14 and 4*	5 0 0
If boarded, and the underside levelled and plastered	15	7 10 0

Mr Eyton, very properly, calls attention to the various thicknesses or depth of floors, as representing either more or less increased cost of walls, or gain or diminution in head room between floor and ceiling, and this is a factor not always sufficiently taken into account in comparing the cost of different methods of floor construction.

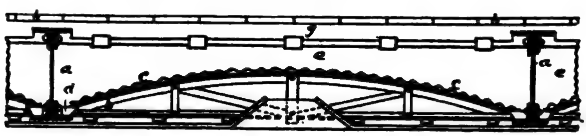


FIG. 44.—Moreland's Floor.

In 1867 Moreland patented a system of floor construction (Fig. 44) in which curved iron or steel trusses rested on the bottom flanges of iron beams for the purpose of supporting galvanised corrugated iron sheets on which concrete was deposited, and floor boards nailed to wood strips fixed to the joists: *a a* are steel beams; *b*, curved truss; *d*, bricks in a continuous line for the ends of the corrugated sheets to rest on; and *e*, concrete. The arrangement was varied to suit special requirements, wood ceiling joists being used if necessary.

* Thickness at springing and at haunches, and at crown.

The floors I constructed of concrete in 1869 and for some years after, were of an ordinary type, concrete deposited on a platform supported on wood centres, which were released after filling in concrete fair or flush with the top and bottom flanges, and upheld by a temporary plat-

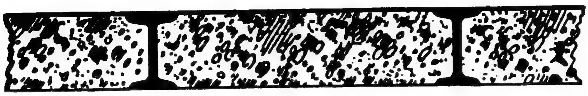


FIG. 45.—Solid Floor.

form or centering beneath, as Fig. 45, and which came into use almost coeval with the adoption of concrete walls, 1865-6.

But as with walls, so with floors; very little care or common-sense was taken in their construction, and with the usual result; one at Portsmouth collapsed in 1876 killing four workmen who were beneath; similar accidents took place in other parts of the country, and concrete got a bad reputation.

Where the joists were much deeper than was required for the concrete filling, earthenware tubes were sometimes

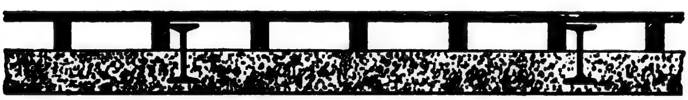


FIG. 46.—Fire-Resisting Ceiling.

embedded longitudinally in the concrete, a system based on Beardmore's invention in 1848, and shown on page 176 *ante*, for reducing the weight of the floor. Another method to effect the same object was to fix wood joists on top of the concrete, as Fig. 46, a very simple arrangement which would occur to most people, but which could scarcely be called a fire-resisting floor but a fire-resisting ceiling, which in case of fire might prevent its upward progress. Still another method was to notch the wood joists over the steel

joists with a view of giving some elasticity to the floor, as Fig. 47. This arrangement did not prevent dirt, dust, and floor washings from finding their way through the joints of the floor boards, and there finding a resting place for generations to come, and from a sanitary point of view was no improvement on the ordinary wood joist and floor board system.

An arched section of floor, as Fig. 48, and stilting the

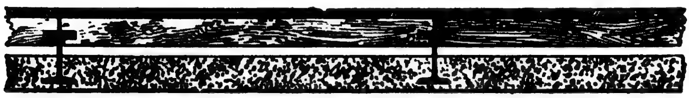


FIG. 47.—Fire-Resisting Ceiling.

beams, is a good form of construction where a level ceiling is not required. The steel joists are strengthened and rendered fire resisting, and it is an economical and light method.

The Americans—on the authority of an American writer—adopted a primitive form of floor with cast-iron beams and brick arches between, so far back as 1850, even

FIG. 48.—Arched Floor.

then a long way behind their English prototypes. Rolled-steel joists appear to have come into use in America in 1855, the solid brick arch being still adopted, and no protection given the beams.

The first use of hollow brick—or tile, as more commonly designated in America—flat floors, were commenced in France in 1868, and to some extent in New York, Chicago and St Louis in 1873-8, and all apparently

based on Pritchett's principle of 1820 or thereabout shown on page 165.

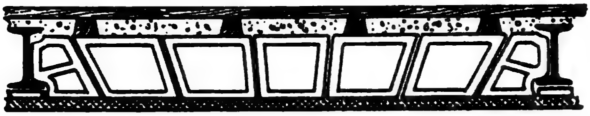


FIG. 49.—Pioneer.

Some American types of floors, adapted from Pritchett's, are shown by the Pioneer and Maurer.

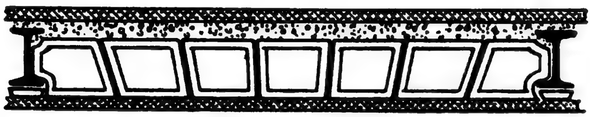


FIG. 50.—Pioneer.

The Doulton-Peto floor (Fig. 53), introduced by Messrs Doulton soon after the American Maurer floor came into use,

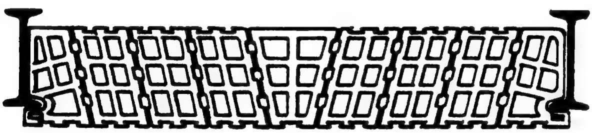


FIG. 51.—Maurer.

was used at the London Pavilion, Whiteley's, and other buildings, and as will be seen is in all respects similar thereto.

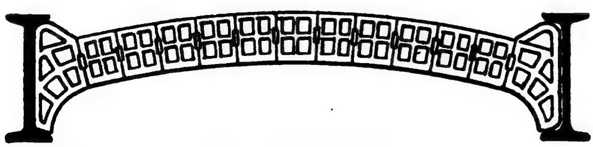


FIG. 52.—Maurer.

A gradual increase in the use of rolled-iron girders for floors, and the result of exposure to the heat from buildings

on fire, causing expansion sufficient in some cases to wreck the walls which supported them, and twisting and buckling the girders themselves in all directions, rendered it apparent that the whole of the iron should be protected with some proper fire-resisting material. Mr Lewis Hornblower, an architect of Liverpool, devised a very ingenious arrangement for this purpose in 1873, as shown by Fig. 54; *a* is

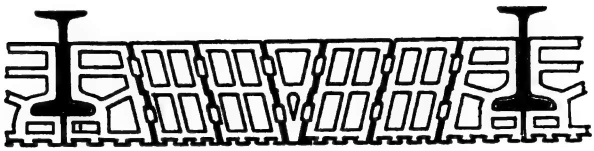


FIG. 53.—Doulton-Peto Floor.

a rolled-iron girder, *b* pottery ware tubes, *c* concrete filling round girder, *e* at top, coating of fine concrete, and *b* at bottom an ordinary coat of plastering mortar. The method of supporting the intermediate tubes by the encasing tubes, to relieve the lateral thrust which must otherwise take place, is peculiar.

Hornblower's system was adopted for the Manchester

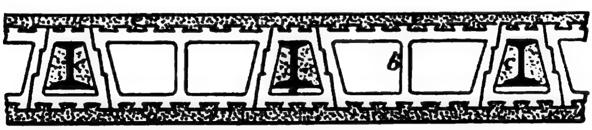


FIG. 54.—Hornblower's Floor.

Pantechnicon, the Liverpool Corn Exchange and many other buildings.

Previously (1871), Mr Hornblower had devised the use of pottery ware tubes, crossing the girders at right angles and resting on their bottom flanges, the space above being filled in with concrete to floor level, or as might be considered advisable.

Here we have the original idea of Fawcett's and other

systems of fireclay lintels to form the ceiling, with a concrete filling, supported by the lintels as a base for the floor. Fig. 55 is a section of Hornblower's 1871 floor. The use of concrete below the tubes was probably considered necessary to protect the bottom flanges of the girders from fire, but the tubes were not slotted at their ends, as is now the case, to allow a portion to pass beneath the bottom

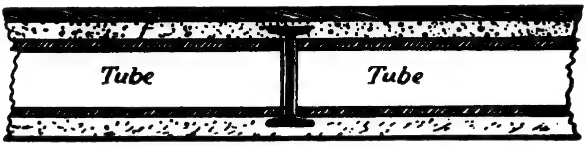


FIG. 55.—Hornblower's Floor.

flanges of the girders. The tubes were arch shaped, and had flat bottoms and vertical strengthening webs. There were different forms of construction according to the span of floors and their purpose. A platform to uphold the concrete was necessary, and this was an obstacle to their extended use.

Mr Robert Swarbrick, of Manchester, at a later date,

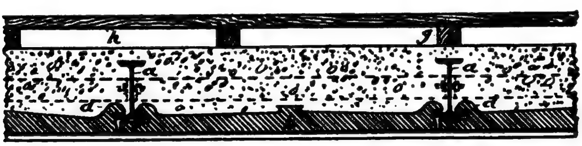


FIG. 56.—Swarbrick's Floor.

1875, rectified Hornblower's error in his 1871 floor with regard to the use of concrete below the tiles and the absence of other form of protection, and otherwise simplified the arrangements, making slabs of fire-clay to rest on the bottom flanges of the girders, which were fixed 18 inches apart or thereabout, and the slabs slotted so as to pass under and protect the girder flange, and leave an air space between the latter and the tile protection.

Fig. 56 shows Swarbrick's system; *a a* are the rolled-iron girders, *b* earthenware slabs; *c* the projection of same to protect girder flange, *d* the lip of slab, *g* floor joists bedded on the concrete, and *h* common flooring boards.

Mr Northcroft, an architect of Liverpool, in 1876 introduced a form of fireproof floor which in some ways was an

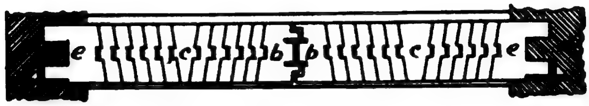


Fig. 57.—Northcroft's Floor.

improvement upon Hornblower's; the blocks encasing the girder were more easily placed in position, and the individual portions were lighter to handle. Fig. 57 is a section of this floor; *a a* are the blocks encasing the rolled or cast iron girder, *c c* keys, *d d* walls, and *e e* wall springers.

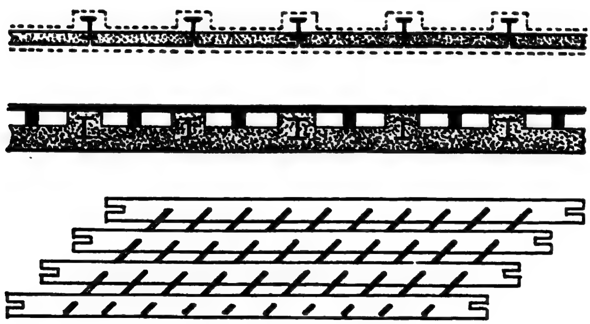


Fig. 58.—Hyatt's Floor.

In the years 1870-5, Mr Thaddeus Hyatt made many experiments with reinforced concrete floors and lintels. One was in using bars of iron notched at the ends to fit the bottom flanges of iron joists; these bars were usually about 2½ inches in depth and placed about 3 inches apart. Through holes in these bars light iron rods were passed,

and a temporary platform being fixed beneath, concrete was filled in from the top.

The concrete was kept below the bottom flanges of the joists, a provision in case of fire. Fig. 58 shows the bars in place, a section of the floor in progress, and after the concrete had been done.

Mr Hyatt made a large number of experiments to

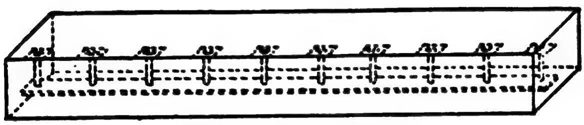


FIG. 59.—Hyatt's Floor.

ascertain the increase in the strength of concrete by the use of iron tension rods embedded therein.

Mr Hyatt did good service in another direction by making experiments with and satisfactorily proving that concrete and iron, when exposed to very high temperature, expanded in an equal degree, or nearly so, one of the most important factors in fire-resisting floors, roofs, lintels, &c.

Another point Mr Hyatt experimented upon was whether

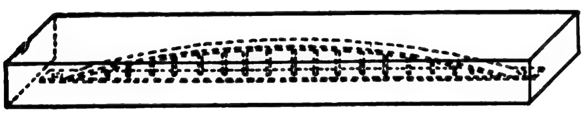


FIG. 60.—Hyatt's Floor.

the tension member of reinforcement, which is, or should be, as near the lower side of floors, &c., as practicable, may with advantage be connected by vertical ties to a similar reinforcement, or to iron washers or plates near the top, to counteract the shearing stress, as Fig. 59.

He also designed trussed construction for reinforcing floors and beams, as shown by Fig. 60.

Altogether Mr Hyatt realised the true principles of floor and beam construction, for he said: "When a beam

is subjected to a bending stress it becomes more or less curved, by virtue of which the outer or lower portion is lengthened and the inner or upper portion shortened in proportion to the depth of the beam or the difference in length between the radii of the curves. Were the beam made up of horizontal layers, the effect of the stress would be to cause them to slide one upon the other, but the beam being solid, the particles are held together by their own cohesion, the shearing strains being thus opposed by cohesive force."

In 1874 Major Seddon, R.E., made a series of experiments at Chatham with a view of determining the strength

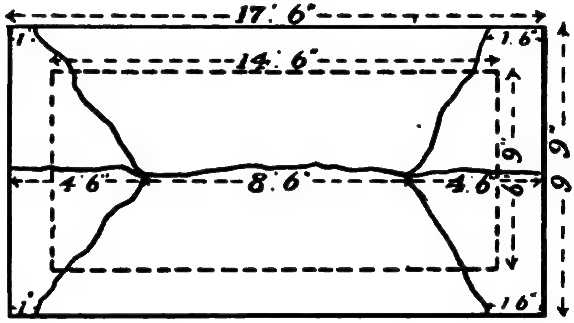


FIG. 61.—Seddon's Floor Test.

of concrete slabs proposed to be used for landings and floors for the Brigade Depôt Armouries. These trials are valuable, insomuch as we are certain that no vested interests were concerned, and that the experiments were made under proper conditions.

It must be remembered, however, that Portland cement is of a much superior character now to what it was thirty years ago, and that similar experiments made at the present time would probably give 50 per cent. better results.

Experiment Fig. 61 shows a floor or slab of concrete 17 ft. 6 in. long, and 9 ft. 9 in. wide, all four sides resting on 18-in. walls, leaving therefore an area 14 ft. 6 in. in

length, and 6 ft. 9 in. in width, unsupported. The floor was 6 in. thick, and made of one part of Portland cement to four parts of broken brick ballast screened or gauged through an inch mesh, well beaten when deposited in place and ultimately covered with water for seven days. At the end of this time, layers of bricks were piled over the entire surface of the unsupported area, until a load of about 11 tons, or 2.22 cwt. per foot superficial, exclusive of its own weight, was applied. At this point the edges of the slab began to rise along the sides, and when loaded with 15 tons, or 3.06 cwt. per foot superficial, it suddenly gave way.

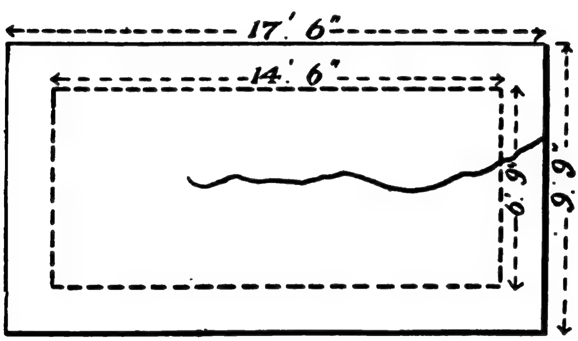


FIG. 62.—Seddon's Floor Test.

This was a decidedly successful result, so far as it went, and a second experiment was made with a slab similar in all respects and the conditions also the same, except that an interval of fourteen days instead of seven was allowed it to mature. This slab broke down with about 13½ tons, or 2.75 cwt. per foot superficial, distributed in the same manner as before.

Considering that neat Portland cement tests usually give about 20 per cent. increase of strength in fourteen days compared with those of seven days old, this result is somewhat unsatisfactory, but at any rate it goes to show that a large factor of safety should always be allowed in concrete floor construction.

The next test was with a similar slab, the conditions still the same, except that twenty-one days were substituted for seven and fourteen days. A party of forty-five men marched on to it, marked time at quick and double, then jumped. This having no visible effect, it was loaded with bricks as before, and when 15 tons, or 3.06 cwt. per foot superficial, had been applied, it commenced rising off its outside edges; with 32 tons, or 6.53 cwt. per foot superficial, it cracked slightly, and was then loaded up to 43½ tons, or 8.88 cwt. per foot superficial, without any appearance of the crack altering. At that time it had tilted up about ¾ inch at the outer edges. No further attempt was made to break down this slab, and the experiment certainly gives some curious results. Not only does it appear to have attained three times the strength of a similar slab fourteen days old, but after cracking it supported an increased strain without losing strength. This entirely disproved the theory at that time common with regard to concrete; first, that it is capable of no sensible deflection without rupture; and secondly, that when once rupture has occurred, or cracks are visible, the end is not far off, and it loses its capabilities of sustaining a heavy load. Fig. 62 shows the crack as it appeared in this slab.

Two further experiments were also made, all conditions being the same as before, except that fourteen and twenty-one days respectively intervened between the making and testing of the slabs, and instead of one part of cement and four parts of broken brick ballast, the aggregate was composed of twelve of broken bricks, four of cement, and three of sand, and the effect was that 12 tons 6 cwt., or 2.51 cwt. per foot superficial, broke down the fourteen days old floor, and 13 tons 18 cwt., or 2.84 cwt. per foot superficial, the twenty-one days floor, proving that it is a mistake to dilute the aggregate with too great a proportion of sand.

Experiment Fig. 63 was made with a slab of concrete 6 in. in thickness, 17 ft. 6 in. long, and 16 ft. 6 in. wide, out to out, resting on 18-in. walls, having thus a clear bearing

of 14 ft. 6 in. by 13 ft. 6 in., the materials being the same as previous, and the test made when twenty-one days old. A party of eighty men marched on it, marked time at quick and double, then jumped; it was afterwards loaded with bricks as before. There was no result from the jumping, but the slab broke suddenly and without warning under a weight of 10½ tons, or 1.07 cwt. per foot superficial. Fig. 63 shows the cracks as they appeared at the time of rupture.

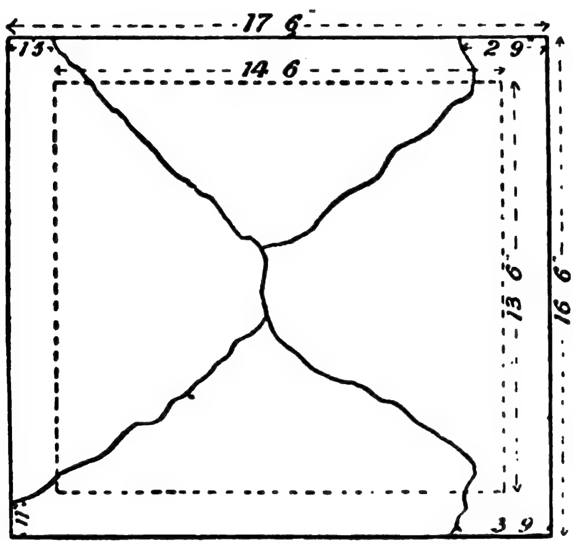


FIG. 63.—Seddon's Floor Test.

In this case the result of eighty men jumping simultaneously might have been expected to produce what the dead weight of 10½ tons accomplished, as the shock caused by sudden impact of this nature would be very severe.

Experiment Fig. 64 represents a landing supported on three sides, the concrete being 5½ inches in thickness, and composed of one part of Portland cement, two of broken Charlbury stone (oolitic limestone) and two of broken

bricks and Broomhall tiles. Some of the stone would only have passed through a 1½-inch mesh. The test was made at fifty days old (and in this case appears to have been a piece of work intended to remain), when a concrete beam weighing 270 lbs. was dropped from a height of 4 feet 6 inches, and fell on one corner in centre of landing, the result being a dent ⅛ inch deep; the floor seemed to quiver, and two or three small flakes fell off the under side, which was rough (and would account for flaking), and the beam

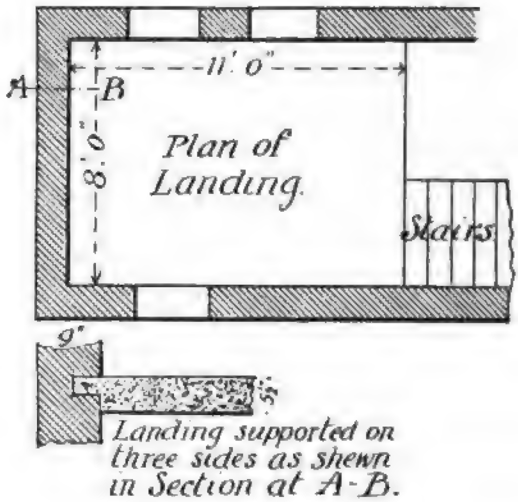


FIG. 64.—Seddon's Floor Test.

broke in two. Another beam, 329 lbs. in weight, was dropped from the same height, and fell along one edge about the centre of the landing, causing a slight line about ⅛ inch deep to be cut in the landing, and a flake or two to drop from the under side as before, but with no other result. The form of concrete, as shown by section, was weakened by being reduced in thickness near the bearings, but after these tests the landing was allowed to remain, and has presumably been in use since that time.

Another experiment was upon a slab 18 feet by 16 feet 6 inches outside to outside, 15 feet by 13 feet 6 inches in the clear, and 6 inches in thickness, and made in the same way as the others. The slab was twenty-one days old, and an iron 4 cwt. was raised over the centre and dropped from a height of 4 feet, the result being that it broke a hole clean through the slab, but no radiating cracks appeared, nor did the other portion of the slab seem injured. The result was probably unexpected, but it tends to disprove a notion still entertained that if a concrete floor experiences a sudden and violent concussion its collapse *en masse* will result.

Experiments rectify another assumed error, viz., that there is no elasticity in concrete. If the slab 9 feet

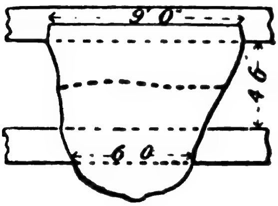


FIG. 65.

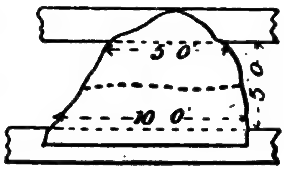


FIG. 66.

9 inches wide had tilted up $\frac{3}{4}$ of an inch in 18 inches (the thickness of the wall) it must have deflected at least $2\frac{1}{2}$ inches in the centre; it is a pity that this was not definitely ascertained.

It has been stated that one of the effects of reinforcing floors is to create this elasticity of concrete; Major Seddon's experiment proved that it existed without reinforcement, and in my own experience I have found this also, but reinforcing considerably increases the amount of elasticity.

Figs. 65 and 66 represent portions of the broken floor, Fig. 63; the one having a clear bearing of 4 feet 6 inches was broken with two weights each of 56 lbs. dropped together from a height of 10 feet, after previous attempts in the same way from heights of 4, 6, 8, and 10 feet respec-

tively had produced no effect. The other piece, having a clear bearing of 5 feet, was broken by a weight of 150 lbs. with a 6-inch base, dropped from a height of 8 feet, after the same weight had been dropped from 4, 6, and 8 feet

FIG. 67.—Ferguson's Floor.

respectively, the only result being a crack in centre after the 8-feet drop.

A type of hollow fire-clay tile construction floor is shown by Ferguson's, Fig. 67, and which has been in use

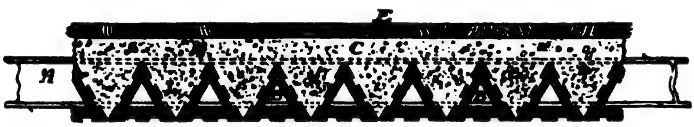


FIG. 68.—Homan's Floor.

about fifteen years. The steel joists are fixed 2 to 3 feet apart; the tubes are slotted to pass under the joists, and the spandrels filled in with concrete in the usual way. Unlike most other floors of this character, there are no skew-

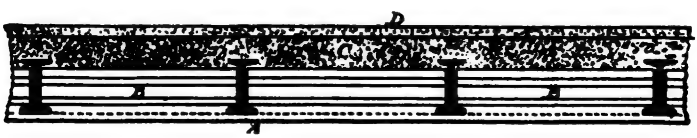


FIG. 69.—Homan's Floor.

backs. The depth of the tubes is 7½ inches in the centre, and the weight of the floor about 19 lbs. per square foot. Dovetail grooves, as in Bunnett's of 1858, give a key for the plastering mortar.

Figs. 68 and 69 show Homan's system of floor con-

struction, or rather one of them, for Messrs Homan have taken out enough patents during the last forty years, one would think, to cover the whole field of fire-resisting

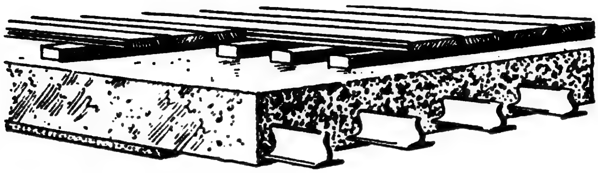


FIG. 70.—Homan's Floor.

floors. The fire-clay lintels are slotted at the ends, as in other systems, to pass under the joists, and the soffits are also grooved for a key for the plaster. Fig. 68 is a section of Homan's floor, and Fig. 69 a transverse section of same.

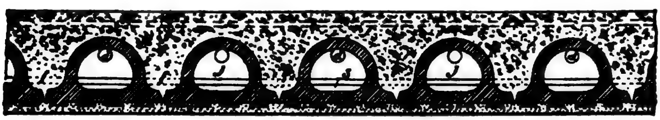


FIG. 71.—Fawcett's Floor.

A A are steel joists, B B tubular lintels, C C concrete filling in on the lintels, D cement finish, and E wood blocks, or wood flooring nailed to the concrete in place of D.

Messrs Homan's latest floor, Fig. 70, is on quite a new

FIG. 72.—Fawcett's Floor.

principle, the object being to link the steel joists and concrete together, and a claim is made that joists on this system possess greater strength than the ordinary kind.

Fawcett's floor, Figs. 71 and 72, is a similar class of

floor to Homan's, the difference being only in the lintels. J J are steel joists, *d d* holes in same for ventilation, L L fire-clay lintels. The concrete takes a bearing on the joists relieving the weight on the lintels. Fawcett's floor was invented and patented in 1888.

The Frazzi floor, Figs. 73 and 74, is formed of fire-clay lintels, with skewbacks of the same material, and concrete

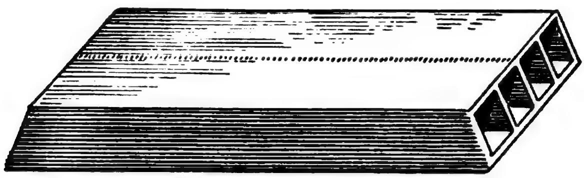


FIG. 73.—Frazzi Floor.

filling on the top as in others of this class. Between the joints of the blocks wire or iron hoop, is inserted to increase the strength.

Another kind of hollow block floor is that of the National Fireproofing Company, in which the blocks are not placed close together, but a space is left between in which concrete is deposited, and a tension rod or other

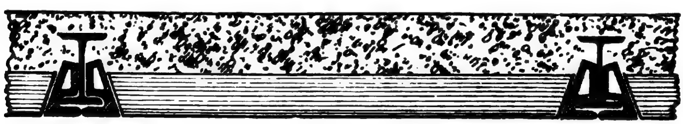


FIG. 74.—Frazzi Floor.

form of reinforcement embedded therein. The Kleine is similar thereto, except that iron or steel bars take the place of rods.

Fig. 76 represents the Columbian floor. The steel joists of the section shown are suspended by hangers over the top flanges, and a filling in of concrete in the usual way. This is a variation of Thusane's floor, Fig. 34, joists taking the place of rods.

Messrs Hodkins & Jones' floor arrangement (Fig. 77) consists of the use of corrugated steel bars or joists without

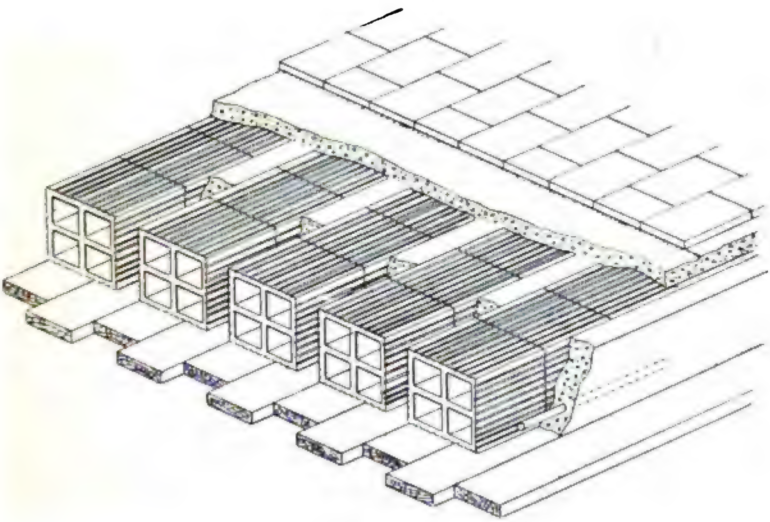


FIG. 75.—National Floor.

flanges, by which means increased strength over common bars is claimed.

Clay bricks or blocks when cemented together form a

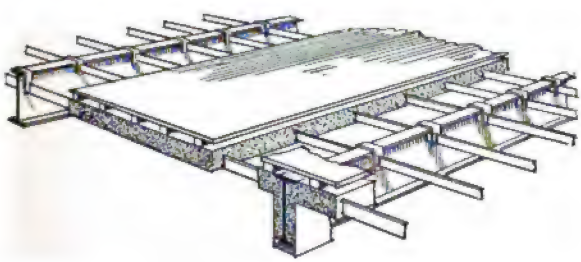


FIG. 76.—Columbian Floor.

beam or floor of great strength and a near approach to concrete of medium quality. The method of testing the strength of Portland cement in its early days was to cement

a brick against a brick wall, then another to that after allowing time for the cement to harden, and so on until the first brick parted from the wall and the whole collapsed. General Pasley relates in his book on "Cements," that on one occasion he joined thirty-one common bricks in this way, the total projection of which was 7 feet and the weight 186 lbs. The cement was manufactured by himself from chalk and clay on the site, and in a very rudimentary way. The result seems extraordinary, but goes to show that perfectly flat floors could be formed of common bricks and neat cement, of considerable size and with perfect safety, but as concrete would cost less there would be no advantage gained.

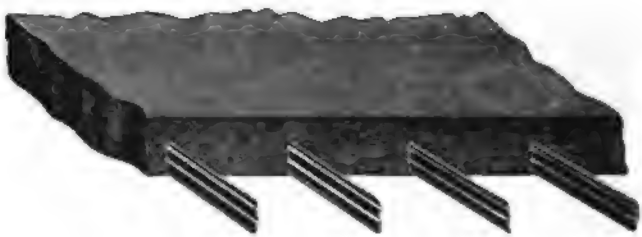


FIG. 77.—Hodkins & Jones' Floor.

American and German inventors have within the last few years introduced a variety of types of fire-clay tubular lintel floors, the limit to which, and the variations in their design seem to be never ending. The manufacture of lintels of this character is being taken up by brick and tile manufacturers to enable builders and others to construct their own floors. Concrete is also being used to make lintels similar in shape and size to the burnt clay types. Many of the burnt clay or cast concrete type of floors are adaptations of Pritchett's floor of 1820, or Frost's of 1840, adapted to modern requirements.

Within the last twenty years the number and variety of fire-resisting floors adopted and patented in this country is beyond calculation.

Some have died a natural death for want of fitness for the object in view; others have been kept alive by means of advertising and persistent push, irrespective of merit; some from gushing descriptions of huge buildings in America and elsewhere where no other system but the advertiser's was used, and none comparable therewith; and others which the owners rely upon fulfilling their purpose, and in so doing commend themselves. In course of time matters will adjust themselves, and Darwin's theory of the survival of the fittest probably applies to concrete floors as well as human kind.

It must not be assumed that the floors illustrated in this article are suggestive of the best. They are only intended to show the progress and changes made in the methods of construction, the materials employed for the purpose, and typical examples of those more generally known and in use at present, but which do not come under the description of reinforced construction.

Most of the systems described are, I believe, the subject-matter of patent rights. It is still believed by many people that a patent is a kind of indefinite assurance that the material or article patented possesses some sort of superiority, whereas as a matter of fact patents are ofttimes the result of theoretical vagaries which in actual practice are quite a failure.

CHAPTER XI.

THE APPLICATION OF CONCRETE TO FLOORS, ROOFS, AND PAVING.

IN applying concrete for floors, no matter whether solid throughout or only as a top covering for terra-cotta or clay blocks, or cement lintels, all of which require to be finished with concrete, it should not be left in an incomplete state between the supports, *i.e.*, walls, joists, or beams, long enough to become set. When work is suspended, for the day more especially, it should be finished against a plank, fixed in the centre of the supports. When the concrete is being deposited in place it should be gently tamped or beaten, preferably with a flat bottom tamper about 8 by 8 inches, but not left for a time until initial set has commenced. Violent beating should be avoided, and tamping only sufficient to produce homogeneity be practised. The effect of violent beating is to bring some of the cement and excess water to the surface; the water eventually goes back again, or is sometimes sopped up by the workmen with flannels. A portion of the water unnecessary for hydration goes through the joints of the centering, or forms, which should be kept slightly open when fixed, to allow for this, and for expansion of the forms. If the water is discoloured by the cement, it is direct evidence of too much having been used. The concrete should not be too dry; it was assumed at one time that only water enough to make the cement adhere to the aggregate was advisable, but this renders homogeneity more difficult. Experiments made by the United States Government

proved that the strongest concrete was of a sloppy character.

The R.I.B.A. Committee advises that concrete should be deposited in 3-inch layers—an American custom, but not a desirable one.

If a floor is 6 inches in thickness, in two 3-inch layers, the bottom one, as the result of tamping has a comparative smooth surface, and the larger particles of the top layer are unable to bond with the bottom.

Floors are subject to so many sudden and varying forms of stress that the perfect bonding of the concrete materials is an important factor. Another practice is to specify that the aggregate is to be of small dimensions, not exceeding in some cases $\frac{3}{4}$ inch for the maximum and $\frac{1}{8}$ inch for the minimum diameters, presumably with the object of attaining perfect solidity, coarse sand being added to help to effect that object. But for solidity to be effective the materials must bond with each other in the best possible manner, and it is only by using an aggregate of varying sizes that this is obtained—say from the size of coarse sand to that which will be refused by a $1\frac{1}{4}$ or $1\frac{1}{2}$ mesh screen for floors 6 inches in thickness, increasing or diminishing *pro rata* to their thickness and the nature of the aggregate.

It is most desirable for floor concrete that the aggregate should be of a suitable consistency; if it contains a large amount of sand the concrete is weakened through the cement having too much work to perform; if on the other hand there is too small a proportion of finer ingredients, homogeneity cannot be secured. Excess in either direction is a source of weakness in floor as in wall construction, and this is one reason why coke breeze is not the best of aggregates, although there are materials used which are worse.

If concrete floors are executed in hot weather, and the sun is shining on the work, the concrete should be covered as soon as possible with wet sacks, tarpaulins, or anything

that will keep off the sun's rays; if a storm comes they will also prevent the rain from beating the concrete and washing away a portion of the cement. A thunder-storm on a newly executed concrete floor may do much mischief; to avoid this it is an excellent plan to mix up cement grout in buckets, and pour it over the surface as the work proceeds or soon after; it fills up the interstices, sets much quicker than the body of concrete, and under any circumstances is beneficial to the latter. A few buckets of grout will do a considerable amount of floor area.

After being deposited for some hours, to allow of partial set, it is desirable, more especially in hot weather, to keep the concrete well watered and continue watering at intervals for several days; this retards the setting and increases the ultimate strength and hardness of the concrete; it is impossible to keep concrete too wet, except as a matter of course in cold weather when frost may be expected.

In hot weather it is a good plan to cover the concrete with an inch in thickness of wet sand or sawdust, and keep it wet for several days; it is useful, too, in winter as a protection from frost. If the concrete is not covered and rain is not anticipated, grouting with cement about two days after it has been laid gives it a hard unwearable temporary surface, preventing it from being disturbed to any extent by workmen's nailed boots.

Before laying the concrete, strips of wood temporarily fixed quite true to the required level should be arranged about 10 feet or any lesser suitable distance apart and a straight-edge or wood — employed to straighten the concrete from screed to screed.

Where a large area of flooring has to be executed, the economical distribution of the centering, or forms, is an important consideration.

It is desirable, where circumstances permit, to concrete floors in squares, similar to a chess board, leaving the alternate squares to be done after an interval of about two

days. Slight expansion in concrete takes place in the interval and corresponding contraction follows, but after a much longer time. The contraction—should any take place—would be where the squares joined each other; the result would be unnoticed, and the strength of the concrete would not be seriously diminished.

The proportion of matrice to aggregate generally employed is from one to four to one to six; one to five is ample for all classes of work except where the distance between supports is considerable, or the concrete is thin. If not reinforced, an old formula of ½ inch in thickness for each foot of its greatest length of unsupported area, was at one time a rough and ready guide for floors to carry a safe load of a hundredweight per foot superficial, *i.e.*, a floor 18 by 10 feet should be 9 inches in thickness, but which would apply also to 18 by 18 feet, the proportion of concrete materials being one to five.

Reinforcing, however, has made this rule obsolete; but although it increases the strength in many cases, and if well done, approximately four times that of concrete not reinforced, it must not be assumed that one-fourth of the amount of concrete can be employed to obtain an equal result, but that a reinforced floor may be estimated to carry a safe load four times as great as one not reinforced, always assuming that the reinforcement is of a suitable character. It is some consolation to know—in the latter case—that if a failure ensues from overloading or other causes an entire collapse is improbable; the reinforcement should prevent this, and the floor itself would give warning by deflecting considerably before any rupture took place, which is not the case with old timber floors.

The reinforcing material would be capable, too, of sustaining the floor long after its safe limit of expansion had taken place. Where flat solid, or reinforced floors are adopted, coarse sand or fine shingle has been sometimes sprinkled over the form boards—with a view of giving an even and suitable key for the plaster ceiling before

depositing the concrete in place, and which is generally unsuccessful, as either the material has been found quite loose when the form boards have been removed, or the concrete has a smooth surface through the cement percolating into and uniting the particles. It is impossible to deposit the concrete to obtain just the key necessary for plastering; it is found as a rule to be patchy and quite unnecessarily rough in some places, and smooth in others, and as a smooth surface is supposed to indicate that the concrete is sound, the latter is preferred, as a rule, and experienced practitioners should know how to manipulate the concrete with this object. The surface is then hacked with a pointed hammer which simply makes indents in the concrete, but unless great care is exercised, no proper key for plaster. As a result there have been many failures of plaster ceilings on concrete. The better plan seems to be, and which is adopted in many cases, is to use one or other of the patent plaster compositions, or Keene's cement, put on in one coat and as thin as circumstances permit. It is not unusual to see cracks in the plastering of ceilings, in the line of the main beams or joints, the result of slight shrinkage in the concrete. Cracks through shrinkage in the concrete seldom show in the thickest portion, but where it is disconnected or weakened by bearing on steel beams. Ordinary plastering is not so likely to show cracks of this kind, as it is of a more elastic nature, but its weight owing to its thickness renders it unsuitable for plastering ceilings direct on concrete except it is kept thin.

Terra-cotta and concrete blocks or slabs afford no key for a plaster ceiling, unless dovetail grooves are cast on their face; many have only roughened surfaces, quite good enough for wall plastering but affording little or no key for ceiling plaster.

The use of soap, or fatty oils with which the form boards are coated to prevent adhesion of the concrete, is liable, if in excess, to prevent the ceiling plaster from adhering as it should do to the concrete. There has

been no end of varying opinions relative to the contraction and expansion of concrete floors. It may be safely assumed, I think, that the aggregate alone undergoes no change; possibly the addition of water may cause expansion in certain aggregates to an unmeasurable extent. Cement, on the other hand, usually expands slightly, and so therefore must concrete, unless we assume that its particles undergo slight compression arising from the action of the cement, and which is not improbable. My opinion is—and I find it coincides with that of others who have had much practical experience with concrete—that the latter expands slightly when first deposited in place, but when the permanent set of the cement has taken place, say within forty-eight hours, it ceases, and as a large floor is usually some time in hand the bulk of the concrete has passed beyond the expansion stage before it is completed. How long it is before contraction takes place seems to depend on surrounding circumstances.

Where unseasoned cement has been used for floors and flat roofs, expansion may not develop for months, or even for years, for the action of cement is erratic, and often not easy of explanation.

With unseasoned and ill-conditioned cement there is no limit to the mischief of which it may be the cause, both to concrete and to brick walls built with cement mortar. It will fracture brick and stone walls up to two years after completion, and possibly longer—the former is within my knowledge.

I have known horizontal cracks of this character appear in brick walls, when, for want of some better explanation, it has been suggested that the flat roof concrete has expanded sufficient to upheave the brickwork. Obviously the greater the proportion of sand the less liable cement mortar is to expand.

Where the load or dead weight is diminished, as for instance near the top of parapet walls, or top of boundary and similar walls, horizontal cracks do not as a rule run

the full length of the latter, but at irregular intervals and perhaps 5 to 10 feet in length, and when these are in evidence there is no question as to the cause. The pointing may be raked out and the joints repointed, but there is no certainty how long the latter will remain sound. The mischief is more in evidence where lead flashings are turned or tucked into the brickwork joints; if the cracks occur at these joints, rain invariably finds its way in the wall and down to the ceiling, or whatever may be under, and disfigures the walls. At once the roof is said to leak.

When the walls of buildings have been erected with cement mortar, and the floors are concrete, the cement for the latter being of a suitable description and the cement for the former the reverse (failures of the kind have occurred), the result is invariably put down to expansion of the concrete, and the floor contractor possibly becomes an innocent victim to damages.

If, however, the cement was of the same inferior quality for both walls and floors, the resulting failure is obviously increased, as the latter assists in straining the walls or lifting the bricks off their bed. In walls of this character where there are possibly no concrete floors, and vertical cracks occur, more generally near the ends or adjacent to window or door openings where there is the least resistance, the foundations at those points are sometimes assumed to have sunk, and underpinning has taken place.

Where large concrete floors are formed, the expansion if ever so minute, should be seen in the mortar joints of the walls upon which the floors bear, but I have never found this to be the case where proper cement was employed; the most satisfactory trial of the kind in my own experience was with a number of floors 120 feet in length and 26 feet in width; some were formed between steel joists 4 feet apart, others rested on dwarf walls, and not the slightest sign of expansion was apparent five years after in any of these floors.

A curious form of failure in floor construction occurred

to a large public building about two years since, the authority being the clerk of works; the circumstances were well known locally. The floors were finished during the autumn; when summer came the concrete commenced to expand, and when winter arrived the expansion stopped, and it was thought the trouble was over, but the following summer expansion commenced again, with the result that in some cases it amounted to 2 inches in 20 feet. The cement had, it appears, insufficient time to season, it was of Belgian manufacture, probably a natural cement; it may have been over-limed, or magnesia may have been greatly in excess, or an unfortunate chain of circumstances may have been the cause. So far as I know it was an unprecedented case.

When the floor contractor is not the general contractor, and the walls are built with cement mortar, it would save the former trouble in case cracks should appear in the walls to insert wood expansion strips round all floors before commencing, as was the practice when plaster of Paris was the matrice, and removing them when the concrete was set, filling in the cavities with sand, and calling the attention of the architect or clerk of works to what had been done and the motive thereof. The cost is trifling, and future troubles need not then interest the floor contractor.

The methods of finishing the surface of concrete floors are numerous, and depend upon the purpose of the floor. Where a wood surface is required it was a custom at one time to embed dovetail blocks or strips of wood in the concrete to nail the boards to, keeping them quite, or nearly flush with the concrete. The confined damp of the concrete and the warmth of the building are quite certain —sooner or later—to cause dry rot, usually sooner.

Some of the fine fibrous plaster ceilings of the Glasgow Municipal Buildings were fixed to dovetail wood blocks embedded in the concrete floor over, with the result that the blocks got dry rot, and the ceilings had eventually to be taken down.

In my first and last experience in inserting wood fixing blocks in concrete floors, dry rot took place within six months. Another plan is to nail strips of wood 1 inch or 1½ inch in thickness on the concrete for nailing the floor boards to. This is a better arrangement, and leaves available space for gas pipes or electric wires ; even then some ventilation is necessary, and which must come from an external wall. Holes or notches can be made in the strips, or they can be cut an inch or two short at their ends, and also in their length, or both, to let air circulate, and as a double precaution the strips can have one or two coats of carbolineum avenarius, or some similar wood preservative, applied. But it is most important that the concrete is dry before the boards are nailed to the strips.

Another plan is to nail the boards direct to the concrete, first floating the concrete with cement and sand, one to four, to a true and even surface and as thin as possible. Here again the concrete and mortar must be absolutely dry, or the boards will swell and possibly burst up. It is a good plan, even if the concrete is assumed to be quite dry, to lay some impermeable and inexpensive material on it before fixing the boards thereto, such for instance as electricians' impervious paper. After the boards have been nailed to the concrete, should they go slightly hollow on the surface it is a sure sign the concrete was not dry. Although it is generally assumed that dry-rot will not take place if the timber is exposed to the air on one side, I have known cases where the floor boards were completely perished through fixing them to concrete which was very far from being dry, and within six months of the floors being finished. Narrow boards, say 4 to 5 inches wide, are more suitable for nailing to concrete floors than wider ones.

The best kind of nails for the purpose in my experience are stout French oval wire, or fine sheet floor brads, but the better plan is to try a few of different kinds before commencing. When the boards are secret nailed the best section for the joints is as Fig. 78. A joint of this kind

enables the nails to be driven vertically. If they are driven obliquely they act in the nature somewhat of a wedge and are apt to spalt the concrete.

The cost of labour in fixing floor boards to concrete is at least double that of fixing them to wood joists in the usual way. The aggregate should be ashes, breeze, or soft brick débris, and the proportion one to five. If the matrice is in greater proportion nails cannot be driven into the concrete. Floor boards nailed direct on concrete create a somewhat more clattering noise in walking upon than if nailed on wood joists or wood fillets. I have known hair felt to be laid between the concrete and the boards in a hospital ward to remedy this, but the springy nature of the felt made the nailing very troublesome.

It need scarcely be said that linoleum or floor canvas should never be laid on a wood floor of this description; if so dry rot is inevitable. Patent coverings like Eubolith, made of sawdust and some chemical admixture, are said to be successful.

Fig. 78. — Section of Secret-Nailed Floor.

A serviceable wood floor for cottages is obtained by bedding wood blocks in tar and pitch, the concrete being floated true to receive the same; a suitable mixture is one part of pitch to two parts of gas tar, made hot and poured on the floor, but only to cover a superficial foot or two at a time, and the blocks rubbed thereon quickly before the adhesive material has time to chill or cool. Some practice is necessary to become skilful and quick at laying wood floor blocks, and the surface should be planed over, when a floor is finished, to remove all irregularities. Ordinary deal blocks 9 inches by 3 inches, or thereabouts, and an inch thick, are suitable for the purpose.

It was a common practice at one time to bed blocks of wood on concrete with mortar, and grout the joints with liquid cement. The moisture contained in the mortar and

the grout caused the wood to expand, and sooner or later the blocks became loose. In several instances which came under the writer's notice, dry rot set in, caused by confined moisture, and in a very few years whole floors had to be renewed.

Parquetry laid direct on concrete is another form of floor surface, but somewhat expensive, and therefore only fit for a superior class of buildings. Parquetry floor-layers who do this class of work have usually some special composition for fixing the parquetry blocks to the concrete. One of the earliest to practise parquetry on concrete was Mr Eberhard, who executed a large quantity of flooring in this way with a material which he patented, but the patent has long expired through efflux of time. Its composition was as follows:—50 lbs. joiners' glue, 20 lbs. resin, 2 lbs. boiled linseed oil, 2 lbs. red or white lead dry. The whole was boiled up together and cast in moulds ready for use. The writer can bear testimony to its efficacy; several floors laid with Eberhard's patent glue about twenty-five years since being quite sound at the present time. The workmen poured their material in a boiling condition on the concrete, bedding the blocks thereon as rapidly as possible, and planing the surface over when the glue had become quite hard and firm. About 5 or 6 feet superficial was the most that could be laid at a time.

Granitic surface finish to floors is much used for warehouses and buildings of a similar class, and sculleries and domestic offices of private houses, and nothing could be more suitable. It is usually formed about 1 inch thick, and there would appear to be no object in making it thicker for ordinary internal traffic or footwear, if it is of one consistency throughout, which it should always be. The proportion of materials is usually one part of cement to two parts or two and a half parts of washed granite chips to pass a quarter mesh sieve. In an ordinary way we should wonder why a clean material like granite should require washing. The reason is that the action of crushing

produces an impalpable dust, and this is injurious to cement, owing to its fineness. The washings form a pasty mass of the same character, but different colour, to the washings of crushed brick débris. The granite chips and cement should be intimately mixed and laid in chess-board form, leaving the intermediate squares for not less than a day—longer is better. Too much trowelling is not advisable, it brings the effluent water to the surface, and prevents finishing the work for a time. Sometimes it is advisable to soak up this water with flannels, as it is apt in its retrograde movement to carry some small amount of cement with it, and as a result the surface eventually wears slightly rough.

The edges of the squares should be greased, oiled, or soaped, or a thin piece of brown paper pasted on to prevent them sticking to the adjoining edges, and if slight shrinkage occurs, pulling at each other, causing an unsightly ragged joint.

Granitic flooring is thought by some people to be slippery, but this is not so if it is kept dry, nor is it more slippery than other forms of paving—marble, terrasa, &c.—or as much. But to avoid this, Portland stone, Kentish rag, and Yorkshire stone chippings are sometimes used by preference, more especially for steps and stairs. Neat Portland cement, often employed for repairs to worn stone steps, landings, &c., is more slippery than any. Slag chips were in use at one time for artificial paving, but they form, when wet, a more slippery surface than any quarry stone, eventually acquiring a glassy surface.

Mosaic tile and terrasa chips for floors, if bedded and grouted with cement, often become disfigured from cracks which do not appear until months, and possibly years after the work has been executed. Sometimes these cracks follow the line of the joists supporting the concrete, at other times they are of an irregular shape. In the former case they are probably owing to a slight shrinkage in the concrete where the joists break the continuity; but this does not account for those of irregular shape. The

latter may arise from unseasoned cement, or cement which has not been tested for soundness, both for bedding and grouting; the large amount, comparatively, used for grouting and bedding terrasa chips helps still further to develop cracks.

In the case of mosaic paving the remedy appears to consist of laying it in small portions, leaving intervening spaces for a time before completing the work, or better still, forming the pattern with narrow bands and the general surface into panels, leaving the former as the final portion of the work to be done.

The fine floor of the new booking office at the Waverley Station, Edinburgh, is greatly disfigured with cracks of a variety of shapes, and which did not appear for a long time after the floor was finished. A good floor covering is linoleum laid direct on the concrete. The concrete should be screeded and cemented quite true and smooth with a steel trowel, and the linoleum fastened thereto with composition made specially for the purpose by linoleum manufacturers. The cement must be perfectly dry, if otherwise, dampness rapidly disintegrates the cork and linseed oil of which linoleum is made. I have known linoleum to be quite perished before it had been laid a month; in this case the cement surface had only been finished a few days. On the other hand, if the concrete and cement are dry the best quality linoleum will last for a very long period, even where there is heavy wear, and longer than it would on a boarded floor as there are no joints with sharp edges to cause abrasion. But it should be well and naturally seasoned, which it very seldom is. The longer it is kept and exposed to the atmosphere unrolled and laid out flat, or the rolls opened out, in a dry building, the more durable it is when laid, and in addition, shrinkage prevented. New linoleum always shrinks somewhat when first laid, leaving slight fissures round the room between the linoleum and wood skirting and in the joints, and in which dust is sure to accumulate. From a hygienic point of view, linoleum on

concrete forms the best of floors, while the cost of labour of keeping it clean is not one half that of a wood floor.

Cork carpet, which is linoleum less heavily rolled, is suitable for bedrooms and offices where the wear is not excessive; it does not possess so much durability as linoleum, but is softer and more noiseless to walk upon. Obviously the cheap, thin qualities of linoleum and cork carpet will not bear near the same amount of wear and tear as the thicker. The quality of linoleum and cork carpet is one of thickness; that which is sold for about a shilling a superficial yard and is under $\frac{1}{8}$ inch in thickness is totally unreliable.

Concrete flat roofs differ very little in method of construction to floors. Necessarily they have to be covered with some material that will resist change of form from climatic influence, usually asphalt, or one of the cheaper materials of "Vulcanite" character. The earlier concrete roofs were cemented only, and when contraction from low temperature took place they cracked and the roofs leaked. The fall or inclination of asphalted concrete roofs is usually about $1\frac{1}{2}$ inch in 10 feet, but there is no hard and fast rule in this respect. Channel and trough gutters to carry the water to the outlets are seldom used; they effect no object and serve no purpose, and in the neighbourhood of trees are apt to get choked with leaves.

The usual thickness of asphalt for roof flats is $\frac{3}{4}$ inch or 1 inch, the claim for the latter being that it is proportionally stronger to resist expansion and contraction. Only the best asphalt should be employed, such as imported from Seysell, Limmer, and other parts of France and Switzerland, and as there is a good deal of inferior material being used the greatest care should be taken in the quality and the reputation of those to whom the work is entrusted, for, above all things connected with a building, an ever-recurring leaky roof is the worst. The outlets for rain water are either swan-neck lead bends to discharge into rain-water heads, or the asphalt is carried through the

external walls about 9 inches in width and projecting about 2 inches beyond the face of the wall. A piece of sheet lead is usually embedded in the asphalt to turn down near the end and project an inch or less below to form a water check. An opening is left in the wall about 6 inches in depth to allow the water to pass through. Sloping roofs are usually formed with steel principals and tee iron purlins, as shown by Fig. 105, Chapter XIII. Flat roofs have asphalt skirtings with an angle fillet at bottom, and which are or should be not less than 6 inches deep, and the top tucked into a joint of the brickwork for about ½ inch. No advantage is gained by making the skirtings more than ½ inch thick.

Paving, which goes by various names—granitic, granolithic, &c.—is usually a mixture of granite chips and cement, but any hard stone answers the purpose, although not so durable as granite. The aggregate should be not larger than would pass a ¼-inch mesh sieve and washed to eliminate the dust which clings to it. Formerly it was used much larger, but experience proves that the size stated is, all points considered, the best. The proportion is usually one of cement to two or two and a half parts of chips. For ordinary purposes 1 inch in thickness is sufficient, but for very heavy wear 1½ inch is sometimes considered necessary, and for stables and similar places 2 inches.

Where no concrete is necessary, as for basements, courtyards, footways, &c., the ground upon which it bears must be quite solid and levelled true that the paving may be of uniform thickness throughout. It is an advantage to spread a few inches of coarse, dry, broken bricks, furnace ashes, or similar materials well beaten to form a bed for the concrete paving. It absorbs the effluent water from the concrete which otherwise rises to the surface. The latter will occur when the paving is laid on a concrete bed, and if possible it should be soaked up; but if only a moderate amount of water is employed in the mixing there will be but little effluent and it soon disperses. Concrete

paving should be laid in alternate squares, chess-board fashion, as for floors, and measuring not more than 9 feet by 9 feet, and the vacant squares filled in after two or three days' interval. If this is not done irregular fine cracks will possibly occur, a great disfigurement. The squares should be formed true by means of screeds or strips of wood fixed rigidly to the bed and delineating the true finished surface. When the concrete is set the screeds are removed and re-used for a similar purpose. Where the squares join each other it was formerly the custom to insert thin strips of wood between to form expansion fillets; experience has proved these to be unnecessary, but a piece of brown paper should be attached to the edge to prevent the adjoining concrete square adhering, or the edges greased, as described for floors. The grooves in stable paving are usually formed with a piece of hard wood about 9 inches in length having a **V** edge, or with a piece of steel having a **V** edge attached to the wood. The groove lines having been correctly marked on the soft concrete, the tool is hammered in until the groove is formed of its proper shape, and then finished with a steel trowel. This appears to be a rudimentary way of grooving paving, but it appears to answer, on the whole, better than other systems which have been tried. Paving is usually more exposed to climatic influence and rough wear and tear than floor surfaces, and requires very special care to avoid failure.

CHAPTER XII.

REINFORCED CONCRETE.

THE adoption of reinforced concrete, or armoured concrete, or concrete steel, or ferro concrete, each of which means the same thing, viz., the embedding in concrete of steel or iron in the form of bars, rods, hoops, netting, &c., for the purpose of increasing its strength, or the encasement of steel structural work with a view of protecting it from oxidation, has been slow, owing in a measure to the common belief that if iron or steel is buried in a sloppy compound like concrete, it must oxidise or rust. This is however an error, as cement prevents oxidation; it is claimed by some that it destroys rust. However this may be, I have taken steel hoops out of concrete that have been embedded therein for years with not a particle thereon.

M. Monier, a Frenchman and a gardener by trade, wishing to make some cement or concrete vases, found that by embedding wire netting or rods, crossing each other and wired together at their intersections, the strength of the materials was very much increased, and in this way Monier is generally credited with being the originator of concrete reinforcement.

Monier's first patent is dated 1855, and was for the reinforcing of pots, vases, &c., and at a later period for floors, roofs, and other portions of buildings, but, as previously stated, the use of rods, bars, &c., embedded in concrete or *beton* had been adopted in Paris years previous.

Mr Buckwell, a plasterer, executed the basins in the

nave of the Crystal Palace in 1854-5, and in a very similar way embedded rods and hoops in the concrete.

Hennibique, a Belgian engineer, and Coignet, a Frenchman, by ingenious arrangements of the metal, based on mathematical calculations for obtaining a maximum amount of strength with a minimum amount of materials, put the matter on a sound basis. M. Coignet patented his principle in 1855, and the same year M. Lambot originated a novel application of reinforcement for concrete planks for shipbuilding in place of wood, and made a small boat or punt in this way which was exhibited at the World's Exhibition in Paris in 1855, and which is said to be in existence and in use still. The Marine Department of Toulon took the matter up, but their report dated 5th November 1855 was unfavourable. Coignet's system originally differed very little from that of Vaux's, Thusane's, and others, as his description shows, which reads as follows:—

"This new description of flooring is established by laying on the walls to support the flooring a certain number of iron stop planks, parallel one to another, and reposing on the walls by their ends, so as to be completely supported by the whole thickness of the wall. The number and strength of the said iron planks is in proportion to the pitch and to the area of flooring to establish; for instance, for a flooring of 15 feet to a side, or 225 square feet, I have employed three iron planks 4½ inches deep, of which 3 feet weighed about 22 lbs.; but instead of iron planks I can establish iron rods placed at convenient distances apart one from the other, and traversing through and through the four walls supporting the flooring, so that these iron rods cross symmetrically one another and look somewhat like a chess-board. These rods, being in the shape of a screw, and having a nut at each end, will prevent the walls from losing their perpendicularity. Should the flooring have a great span and a large area, strong iron beams would be placed at convenient distances, and the iron planks and rods would rest on the beams."

Cottinceium in 1889, Edwards in 1891, and Hennibique again in 1897, patented further improvements in the same direction. Edwards demonstrated how it was quite possible to make reinforced beams of concrete 50 feet in length.

As a matter of fact, steel reinforcement has been the subject-matter of so many patents, and used in so many different forms, many of which were anticipated years previous, that it is doubtful what proprietary rights now exist, so far as floors and beams are concerned. Obviously all patents that were in force previous to 1894 are invalid, unless they have obtained an extended life, their tenure of existence having expired.

Mr Marsh, in his book on reinforced concrete, says: "Reinforced concrete construction is at present mainly in the hands of patentees of different systems, and of firms who have patented some details of construction and made a speciality of this kind of work. It appears at first sight difficult to design and carry out a structure of this nature without infringing some of the many patents. It will be found however that the really valid patents are, generally speaking, those for some small detail, and that the main principles are not patented and are in fact unpatentable. There are many ways of embedding iron or steel in concrete to obtain the results required, and if one form is patented, and the patent is valid, there are other forms which could be adopted just as good."

It is a mistake to assume that a certain form or system of reinforcement is adapted for every description of beam and floor; what is suitable for deep beams is not applicable to shallow floors. Some are required to carry heavy loads as for warehouses, others much lighter as in domestic buildings and offices. In dealing with floors I do not for present purposes include beams which are correctly speaking supports for floors.

What is most required in a general way, is fire-resisting floors that will combine strength with lightness and economy of cost, and well-directed reinforcement should

enable this to be possible. A few years since 9 inches was considered quite a moderate thickness for ordinary floors, the result being an enormous weight on walls and foundations. A concrete floor, like all other floors, is subject to two direct opposite strains, or as better known in engineering formula, stress, the stress being the force exercised and strain the result of stress. These two opposite forces are divided by an imaginary line equidistant from the top and bottom surfaces, or approximately so, for it varies according to circumstances, and is called the neutral axis. When loaded, the lower part below the neutral axis is undergoing a tensile or pulling asunder stress, while the upper part is at the same time subject to a compressive stress, and both diminish as they approach the region of the neutral axis, where they cease. The tensile strength of concrete is usually considered to average about 10 per cent. of its compressive resistance, and the object of reinforcement is, as far as practicable, to balance these forces. Like most other factors in concrete construction, however, the calculations for effecting this object are not always correct; so much depends upon the concrete, the materials of which it is made and its quality generally. The compressive resistance is often very much greater than calculated, and *vice versa*, as experiments have proved.

Without reinforcement, the upper part—the portion above the neutral axis—is therefore the main factor of strength for load carrying purposes, while the lower half—the portion below the neutral axis, can only be credited with the assumed 10 per cent., from which has to be deducted the weight of that portion of the concrete. Practically it can only be considered as a deferred factor, as the floor or beam is as a rule brought into use long before it has attained its maximum strength.

Professor Hatt's experiments with regard to the position of the neutral axis in reinforced beams proved that in a beam 12 inches deep, and the tension rods 2 inches from the soffit, or under surface, it was 4.36 inches from the

surface when 1¼ per cent. of reinforcement was employed, and 5.47 inches when 2 per cent. was used, so that the neutral axis, for all practical purposes, is midway between the top and bottom of floors and beams. Mr Charles P. Marsh says, however, that the neutral axis of beams with floors attached is about one-third of the distance from the top, but varies with the amount of steel reinforcement.

The maximum tensile stress occurs at the lower face, or soffit of the floor. This points to the necessity of the reinforcement being placed as near the under side of the concrete as possible; but fire has to be considered, which might seriously affect the strength of the concrete reinforcement, and 2 inches from the exposed face is usually therefore taken as a safe distance to place it. But the ceiling plaster affords much additional protection, and if a steel lathed hanging ceiling is provided with a hollow space between it and the concrete, it must be a very severe fire that would have any great effect upon the reinforcement, if only 1 inch in thickness of concrete is provided, or even less.

Moreover, the tension bars may be turned up at the ends from a horizontal direction, and some portions would be therefore removed from danger, although in the same way that the strength of a chain is that of its weakest link so the strength of reinforcement depends on its weakest part.

But a fire in a domestic building is not usually of that virulent character and intensity which is unavoidable in a warehouse stored with inflammable materials. As a matter of fact there should be little to burn in a fire-resisting domestic building, except the doors and windows and the furniture, and which a steel lathed and plastered ceiling would alone protect.

Mr Hyatt found from experiments he made that iron and concrete expanded and contracted from change of temperature in almost an equal degree, and Kinit Styffe's experiments proved that steel increased in strength between

212 and 392 degrees Fahr.; Mr Barba found it increased 30 per cent. in strength at 400 degrees Fahr., and Sir N. Barnaby in his Admiralty experiments says that B.B. boiler iron and Bessemer steel were at their maximum strength at a temperature ranging between 490 and 550 degrees Fahr., so that the effects of an ordinary fire on reinforced concrete may not be so serious a matter as one would expect.

When impact occurs, such as would happen in a crowded ballroom, or through heavy loads being suddenly dropped on a warehouse floor, a violent but momentary bending stress takes place, more especially if the floor is at all weak, and as a result elastic, and which may in some instances possibly affect the rigidity of the reinforcement, and the grip of the latter on the concrete becomes weakened, causing it to have a tendency to slide. Various methods have been adopted to remedy this and to make the extreme ends of the rods or bars immovable. Wilkinson in his first patent used steel rope reinforcement, and this in itself provided a key or grip on the concrete for its full length, but which—as a further precaution—he increased by bending the ends and anchoring them to the concrete.

But steel rods, bars, or hoops have smooth surfaces and do not provide this grip, but their adhesion to the concrete is—all the same—much greater than might be anticipated; some authorities give it as low as 50 lbs. per superficial inch of reinforcement, the R.I.B.A. Committee on reinforced concrete 100 lbs., other authorities up to 500, that is to say a quarter-inch diameter steel rod, 20 feet in length, would have approximately a superficial area of $20 \times \frac{3}{4} = 15$ inches $\times 50 = 750$ lbs. at the lowest calculation, while the elastic limit, that is the stress that could be put on a steel rod of that dimension without elongation, is very little more.

On this hypothesis, steel rods should be able to take care of themselves when used as reinforcement, if the cohesion of steel and cement could be relied on, but it is

unadvisable to assume this, for if any movement took place there is no remedy, and they are for ever after valueless.

There can be no doubt that metal reinforcement, wherever possible, should be small in size and evenly distributed in the concrete. The latter diffuses the strength generally —the stress is not taking place at certain points only in the concrete and not in others, and much greater superficial area for adhesion is obtained; for instance, two $\frac{1}{4}$-inch diameter rods give the same sectional area as one $\frac{1}{2}$-inch, but together are only half the weight and cost.

The amount of reinforcement necessary for floors or

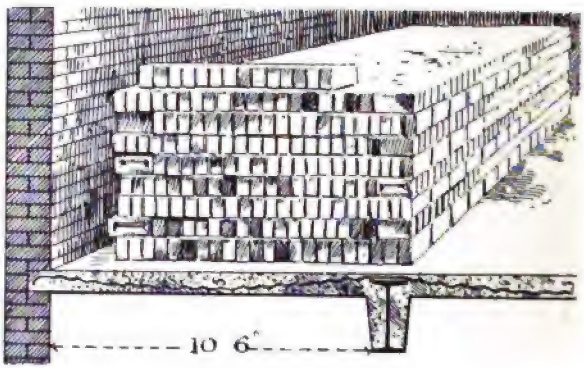


FIG. 79.—Floor Test.

beams depends as a matter of course on the load they have to support, but 1 to 3 per cent. of the combined sectional area of the steel bars, compared with the sectional area of the floor or beam, is the usual proportion. Professor Hatt's experiments showed that 1 per cent. of steel increased the normal strength of the concrete three times, and 2 per cent. four times, so that apparently the strength is not increased in direct ratio to the reinforcement. This test is assuming that the latter was near the under surface; the more it recedes therefrom, the less effective it becomes.

Round steel rods or bars are preferable to others for reinforcing concrete floors, because they can be more readily

squeezed into the soft concrete than square or flat ones, and the addition of concrete on top completely encircles them, leaving no vacancies, and they are readily cut to length or curved.

Some years since Mr Edwards invented a plan of anchoring the ends of tension rods by corrugating them for about 6 inches of their length at each end. This I improved upon by corrugating them their entire length, and experiments have proved that in this way each

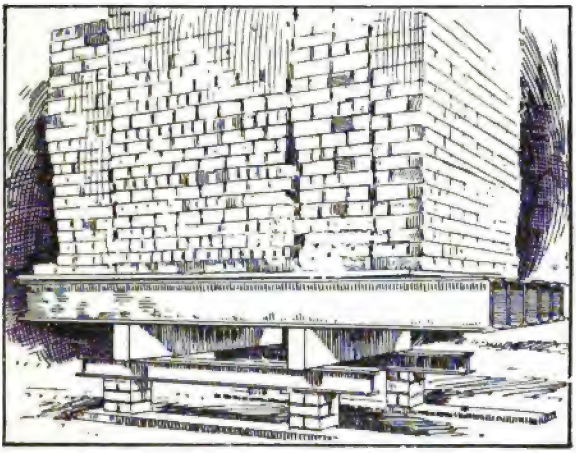


FIG. 80.—Concrete Lintel Test.

corrugation becomes rigidly fixed or anchored, and the stress distributed evenly throughout.

The illustration, Fig. 79, taken from a photograph, shows a floor or slab of concrete measuring 10½ feet each way between supports and 5 inches in thickness, with ¼-inch diameter corrugated steel rods embedded therein 3 inches apart, and in one direction only; the slab was loaded with 2½ cwt. per foot superficial without deflection.

A better test was with two lintels, each 9 inches in depth and 4½ inches in thickness, and 4½ feet between supports. They were loaded with 20 tons of bricks—all

that were available, and deflected $\frac{1}{8}$-inch in the centre, but remained uninjured. One lintel was then tested by itself, and which failed with a distributed load of 13 tons.

The result is extraordinary; the concrete was made with ashes from a destructor—one part of cement to four parts of ashes; for some time before it collapsed cracking sounds could be heard coming from inside the lintel, caused by the movement of the concrete molecules.

Another test was made with a concrete slab or floor $22\frac{1}{2}$ feet by 15 feet clear of all supports and 5 inches in

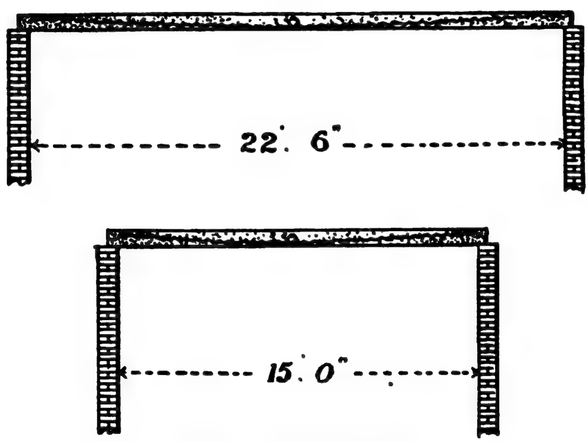


FIG. 81.—Concrete Slab Test.

thickness. Quarter-inch diameter corrugated steel rods were embedded in the concrete. The weight of the rods was about $1\frac{1}{2}$ lb. per superficial foot.

The slab was loaded at the end of three months—at which time the slab was probably about 40 per cent. of its ultimate strength—with about $2\frac{1}{4}$ cwt. per foot superficial, when it began to bend, and continued to do so until deflection of 3 inches in the centre took place, with an estimated distributed load of 3 cwt. per foot.

Slight cracks occurred, starting from the corners and which developed in diagonal lines. No more materials

for loading being available the slab was removed. This experiment, which was made solely with the view of ascertaining the limit of strength of a slab of concrete of these dimensions disarranges all previous calculations. In an ordinary way, without reinforcement, the tensile stress would have probably produced cracks on the under side with an inch or so of deflection. We may reasonably expect, eventually, further developments in strengthening concrete to an extent that may possibly lead to its general adoption in floor construction for every class of building, aided by the enormous demand for timber for paper-making and other commercial purposes which must tend to increase its cost.

Colonel Wynn, R.E., says that concrete unreinforced will not stand elongation of more than 1 part in 10,000 without cracking, but when reinforced, it does not crack when elongated to the extent of 1 in 1,000. It is reasonable to assume that this is to a certain extent a question of the nature of aggregates. Some in their natural state are more elastic than others.

Although almost any form of steel in small sections answers for tensile reinforcement, some sections are better adapted for the purpose than others. Hoops or flat bars divide the concrete wherever they are embedded, and weaken its homogeneity. It is most important, whatever is used, that it should be completely encased in or surrounded by the concrete, and this as previously stated is more easily accomplished by using round rods of small size where practicable.

Expanded steel, wire netting, and similar materials are used a good deal, and weight for weight are equal to most others for tensile stress, but their disadvantage is that no matter whether the distance between supports is small or large, the reinforcement is the same throughout, whereas in many buildings the spans between supports vary a good deal, and if rods are used they can readily be cut to length on the building, or sent the length wanted, and the amount

used adjusted to the requirements of the case, *i.e.*, placed a greater or lesser distance apart to suit the amount of reinforcement necessary. Another advantage is they are cheaper than most other materials. As a matter of fact, the best form of reinforcement is that in which cost, easy application, and efficacy are each taken into account. When the floor to be executed approaches the form of a square and is supported only on its four sides, the most economical method of reinforcement—if the latter is corrugated bars or rods—is to embed two series crossing each other at right angles and at equal distances apart, but where it is long and narrow, as in a corridor or passage, they may with advantage cross the narrow way only, but

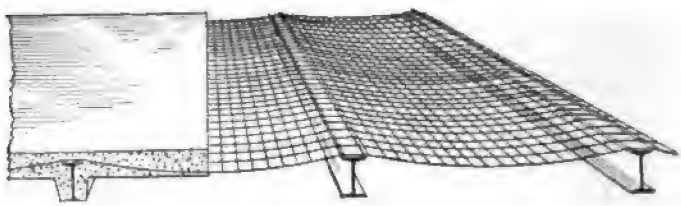


FIG. 82.—Wire Netting Reinforcement.

placing them closer together. There is no necessity to wire them together at their intersections; the corrugations render this unnecessary.

A floor whose sides are alike in length is equally supported by the four bearings, whatever they may be, but if of an oblong shape the long sides take almost the entire load, and the end walls or beams a much smaller portion. Where the space to be covered is of considerable length, but narrow in proportion, steel joists crossing the narrow way at intervals to divide the floor area approximately into squares, may be adopted with advantage where the load to be carried necessitates this additional strength.

The latter is also largely increased where the floors bear on walls, if similar walls are built immediately over them. In that case they become to a certain extent cantilevers,

the value of which depends upon the area of the floor, but where the latter is of square shape and of moderate dimensions the strength is nearly doubled.

Fig. 83 shows an unarmoured concrete slab made in the proportion of four to one. It projected 3 ft. 9 in. from the wall, was 3 ft. wide, and 3 in. thick. A chase or recess was cut 3½ in. into an old wall, and the concrete deposited on a board measuring 3 ft. 9 in. by 3 ft., with a rim 3 in. deep all round, the concrete being well rammed into the chase in the wall and level with the rim. At the end of a year it was loaded with 1,200 lbs. equally distributed, or over 100 lbs. per foot superficial, without deflection or injury. Practically therefore, a passage or corridor floor, 7 ft. 6 in. wide in the clear, made of unreinforced con-

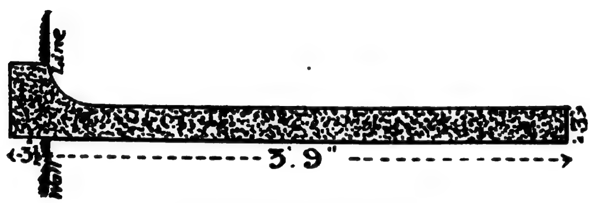


FIG. 83.—Cantilever Test.

crete 3 in. thick, and built into the walls not less than 4 in., might be cut asunder in the centre for its entire length, then loaded with 100 lbs. per superficial foot over the entire surface and still remain intact.

Two steel beams, 20 feet long, were secured at their ends. They were 9 feet apart, and concrete of an arch shape, 4 inches in thickness at the crown—unarmoured—was formed on a wood centre. At the end of a month a chase was cut through the full length. No deflection took place. The concrete was made of cement and crushed bricks, one to five.

An objection to reinforcement of a cross-mesh character is that the meshes obstruct to some extent the complete union of the concrete under and over the metal, unless

much care is taken in depositing it in place; the carelessness of workmen in this respect, except under the strictest supervision, is common knowledge.

The combination of steel and concrete produces curious results. In a reinforced floor described by M. Considere, a French engineer, he found that the strength was much in excess of the reinforcing material and the concrete tested separately and added together. We have examples of similar results with other materials; fibrous plaster made with cheap canvas embedded in plaster of Paris forms slabs of great strength, out of all proportion to the strength of the canvas and plaster measured separately; steel joists may be of such small dimensions as to deflect with their own weight when fixed at a certain distance between supports, but if temporarily supported in the middle previous to the disposal of the concrete between the flanges, and the supports allowed to remain for a week or longer until it has become hard, there will be little or no deflection. If, however, the concrete is deposited on top of the steel joists or beams the result is not the same.

A necessity in connection with the reinforcement of floors is that rods, bars, or whatever may be used, are of sufficient strength to resist the tensile stress without exceeding the elastic limit, that is the limit of resistance to elongation. The stress which should not be exceeded is usually put down at about 15,000 lbs. per superficial inch of sectional area for high-class steel. The French Government engineers say 14,000 to 17,000 lbs., but where floors are subject to impact, 11,500 to 14,000 lbs. With the maximum load to be considered, the total superficial dimensions of the combined sectional area of the rods or bars in inches, multiplied by 15,000, will afford, approximately, a knowledge of what the floor or beam may be expected to carry, the help afforded by the concrete not being taken into account, and always assuming that the limit of compressive resistance of the upper half of the beam or floor is not exceeded. This is usually put down at 1,500 lbs. and over

per superficial inch of sectional area, but much depends upon the character of the concrete; for instance, if the aggregate is of a round pebbly nature and uniform in size, the particles will endeavour to slide or pass each other when under compression, whereas if angular in shape and variable in size they interlock and offer much greater resistance to slipping or sliding.

M. Christophe, a skilful French engineer, says that 6,000 lbs. per inch in compression has been reached, but it was an exceptional result, and that one of cement to five of an aggregate could not be relied on for more than 2,100 lbs. per inch as the limit of resistance. With a safety factor of one in three, 700 lbs. should not, therefore, in practice be exceeded.

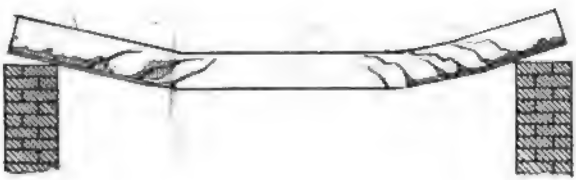


FIG. 84.—Shear Stress.

The R.I.B.A. calculations as to crushing stress on concrete in beams under compression is 2,400 to 3,000 lbs. per superficial inch and the factor of safety five, that is 500 to 600 lbs. per inch. In a general way the weight of steel used in tension ranges from 1½ to 3 lbs. for every superficial foot of floor area, the amount depending upon the strength required and the nature of the reinforcement. If steel rods or bars are embedded in the upper part of a concrete floor they take up a considerable portion of the compressive stress.

Another factor in connection with the strength of concrete floors is the stress produced by the two opposite forces—tensile and compressive—which takes place when loaded, acting in different directions, one trying to override the other, and known as "shear stress." In an ordinary

way we should expect failure in a floor or beam to take place near the centre of both, and which would possibly happen if not reinforced, otherwise the lines of fracture converge towards the top centre at an angle of about forty-five degrees with a horizontal line, and near the end supports. Fig. 84 shows the result of shear stress on a beam tested by the United States War Office. Rankine says that the lines of tensile and compressive stresses are as Fig. 85.

To remedy shear stress, or rather to strengthen the beam or floor by preventing the effects of shear stress as far as practicable, stirrup irons of hoops or rods are often attached to the tension members, sometimes vertically, at other times in a slanting direction, and either relying upon

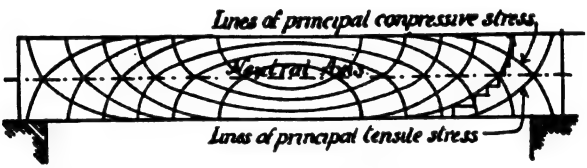


FIG. 85.—Lines of Tensile and Compressive Stresses.

their adhesion to the concrete, or anchored in the concrete by bending or splitting their ends, or suspending them to longitudinal steel rods or bars near the top surface of the concrete, corresponding with the tension rods at bottom, and which in addition assist to lessen the compressive strain on the concrete. In this case the rods forming the compressive members must of necessity be straight, while the tension members may possibly be curved or crooked upwards from the centre. This necessitates the stirrups being of varying lengths, and may cause some trouble and loss of time in their adjustment. In a cutting contract it may safely be assumed that the allignment will not always receive much attention.

Anyway, the extraordinary results of tensile reinforcement unassisted by shearing reinforcement, as shown by

Figs. 80 and 81, is evidence that the former is the main factor of strength.

Obviously a concrete slab or floor, say only 5 inches in thickness, is not so well adapted for shearing reinforcement as deep beams and thick floors, nor as necessary. Iron and steel embedded in cement concrete should not be painted; the cement adheres to the paint and pulls it

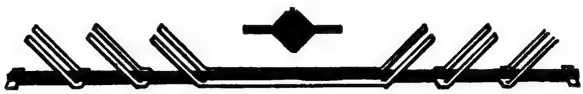


FIG. 86.—Kahn Bar.

away from the metal. It has been stated that rust or steel assists the grip of the cement; others affirm that it prevents cohesion. Probably both are right in a sense, for we know that in the early stages of oxidation the rust can be easily wiped from the metal, but when it has obtained a good hold it eats into and pits it more or less, forming a rough irregular surface and of a necessity weakening its character. In no case can rust be considered an advantage.

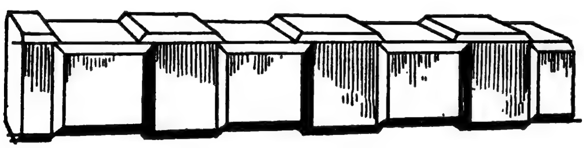


FIG. 87.—Indented Bar.

The Kahn bars (Fig. 86) are steel bars of an ordinary type, split at regular intervals, and portions bent upwards to resist shear stress. The indented bar, Fig. 87, shows ordinary steel bars, indented at equal distances apart to prevent shearing.

In America the Thatcher rod or bar and Ransome's twisted rods are a good deal used. My own view is that corrugated steel rods forming the tensile member and

curved up at the ends, as shown by Fig. 88, serve—for most practical purposes—in plain straight floors to resist the tensile and shear stress in the simplest manner possible up to certain limits.

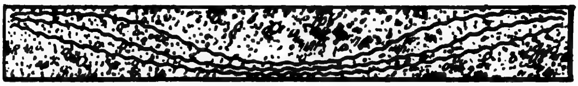


FIG. 88.—Tensile and Shear Stresses.

But there is much to learn yet on this and many other phases of reinforcement and of concrete floor construction generally, as we are made aware by the contradictory statements of patentees, engineers, and concrete specialists, often diametrically opposite.

BEAMS AND COLUMNS.

Reinforced concrete, or ferro-concrete, for beams, columns, and other portions of buildings apart from ordinary simple floors, has certain advantages over rolled steel or iron.

In many cases it is more economical, in others it is not; under any circumstances its use requires a practical knowledge of concrete, the suitable distribution of the steel reinforcement, and approximate calculations as to the value of the various stresses it may be subject to.

We know with comparative exactitude the load a steel beam will carry with safety, but this cannot be said of concrete beams.

Reinforced concrete beams and columns admit of more scope for scientific construction than simple floors. Theory and practice are both essential, for unlike the older systems and methods of building construction, we have only the limited experience of comparatively a few practitioners at the present time to help us.

The tendency at present is to reduce the weight and depth or thickness of floors, and there appears no reason why the latter should, as a rule, exceed 4 inches, exclusive of the tile or wood walking surface and a hanging ceiling if the prevention of sound is of consequence, for domestic buildings and offices where building bye-laws permit. Necessarily the distance between supports would have to be limited, except the use of beams was permissible. But for a certain class of buildings where heavy loads have to be carried, such as warehouses, stores, public buildings, &c., beams are almost unavoidable and sometimes desirable, and, as a rule, are unobjectionable.

Reinforced beams require to be somewhat deeper than rolled steel beams, but if the bottom flanges of the latter are covered by 1 or 2 inches of concrete as is sometimes usual, there is but little difference.

The primary object in beam construction, as with floors, is to strengthen the concrete in a manner to obtain a maximum of strength with a minimum of reinforcement. The usual practice is to insert steel rods near the bottom as with floors but larger, to act as tension rods, and 1 or 2 inches from the soffit, with their ends bent, corrugated, twisted, or fanged, to enable them to be anchored with safety in the concrete, and with or without stirrups or suspenders formed of steel hoops or rods bent round them and fixed vertically or slanting, as may be preferred, and reaching to the top of the beam or nearly so. The top ends of the stirrups are bent to grip the concrete, or as in the Cottinceium system, made to clip over similar longitudinal rods as at bottom, but near the top surface. Fig. 89 is a longitudinal and transverse section of Hennibique's first reinforced system, one rod of considerable size only being used.

Fig. 90 is a later system of Hennibique's, also showing a reinforced column supporting the beam.

Sometimes the longitudinal rods are curved upwards, sometimes not. Whether they should or should not be curved, whether the stirrups should be vertical or sloping—

fixed to the longitudinal bars or left loose, whether transverse ties should be embedded in the concrete, &c., are details concerning which opinions differ. There is little

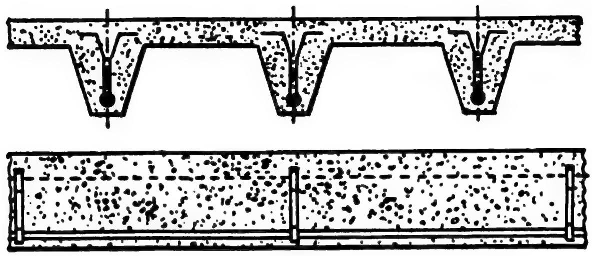


FIG. 89.—Hennibique's First Reinforced Beam.

divergence of opinion, however, as to the advisability of dealing with the ends of the rods in some way to anchor them securely, and not to rely entirely upon the cohesion of the steel and cement. The number and size of the

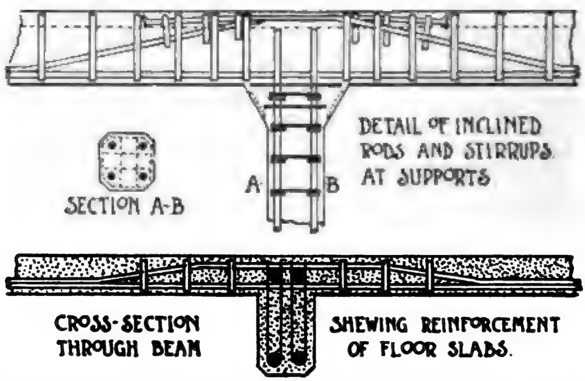


FIG. 90.—Hennibique's Later Reinforced Beams and Stancheons.

tension rods should be regulated—as with flat floors—by the load to be carried, remembering that the safe tension stress is 15,000 lbs. per inch of their combined sectional area, and not taking the concrete into consideration which

is an uncertain factor to rely upon for tensile strength, for beams especially. The longitudinal rods should be as long as possible—not merely cut to the lengths between columns—and hooked to each other where they join. As in floors, the more evenly the reinforcing rods are distributed the better, as the stress is then better taken up by the concrete,

FIG. 91.—Reinforced Beam.

but the distance between the rods should be not less than 1½ inch if large ones; less is sufficient for smaller ones, the main object being to leave no vacuum between the steel and concrete; assuming a beam is, say, only 14 inches in width, the two outside rods 1½ inch from the concrete surface, the rods 1 inch in diameter and 1½ inch apart, five rods would be required, as Fig. 91.

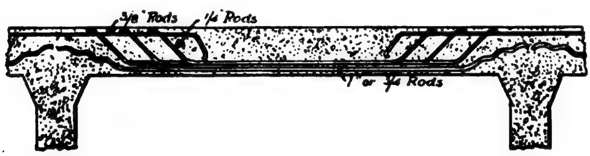


FIG. 92.—Reinforced Beam.

My own view of suitable reinforcement—and which is not claimed, so far as I know, as anybody's patent, is as Fig. 92.

In this floor the tension rods are assumed to be ¾ inch or 1 inch in diameter—as may be necessary, and the smaller ones ¼ or $\frac{5}{16}$ inch; while helping to resist

the tensile strain, the latter act as shear stress members as well. The ends of the rods are best corrugated; if they are only bent up or down, the stress or pull is against a very small area of the concrete, whereas corrugated ends have a much larger area of resistance. If the beams are of considerable depth the tension rods are better curved up at the ends as much as practicable for, say, a fifth of their length each.

If stirrups can be dispensed with much time is saved in keeping them in position while the concrete is being deposited in place.

As will be seen by Fig. 90, Hennibique sometimes uses a trussed form of reinforcement; this form is varied in different ways by other practitioners; he also uses steel hoops for vertical ties in place of rods.

Mr Edwards says that the width of beams should not be less than half their depth, and that no advantage is gained if the depth is more than one-sixth the distance between supports, but that it should not be less than one twenty-fourth. The minimum depth of a beam 24 feet span would therefore be 1 foot; this is too little, except for tie beams. Good results were obtained in experiments made in the United States with reinforced beams 15 feet span, ranging from 10 inches deep and 10 inches wide, to one on the Hennibique system 8½ inches deep and 6½ wide. The former failed with a stress of under 4 tons average, and the latter with nearly as much, but as the safe load should not be calculated at more than one-fourth the breaking stress, the dimensions were evidently too small for general purposes. The beam, 6½ inches wide, failed in the first place by buckling in the middle, which goes to show that reinforced beams should not be too narrow.

But as with steel beams, so with reinforced concrete beams; it appears practicable to span almost any opening provided they are suitably designed.

A "storage building" at Atalanta, U.S.A., described

in *Concrete and Constructional Engineering* for May 1907, is 120 by 60 feet in length and width, and 50 feet in height, with no internal division walls or columns. The roof is concrete 4 inches in thickness, supported by reinforced concrete beams 13½ inches in thickness and 4 feet 2 inches in depth. The beams are spaced at 10 feet centres, and are each reinforced with seven 1-inch and four ½-inch diameter steel tension rods. Down the centre of the building there is a reinforced concrete beam 6 inches in thickness and 18 inches in depth, and which acts as a tie to the main beams.

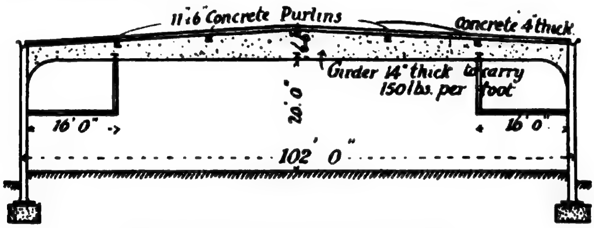


FIG. 93.—An American Roof Section.

We naturally expect to find that in America concrete specialists must go one better than ourselves, and so at Los Angeles, California, a concrete roof has been constructed for a warehouse having a clear unsupported span of 102 feet from centre to centre of the walls, as Fig. 93. The following description and section is taken from Reid's "Reinforced Concrete Construction." The roof concrete is 4 inches thick and supported by reinforced concrete girders or beams 6 feet 6 inches deep at the centre and slope each way 3 feet, the depth at the ends or walls being 3 feet 6 inches. The beams are connected by heavy curved brackets to the concrete wall piers which are 2 feet by 2 feet on section and reinforced by five 1⅜-inch and two ¾-inch steel rods. The girders or beams are 14 inches in thickness and reinforced at the bottom with ten 1½-inch rods of medium steel, two of the rods being straight and the others bent into a hog chain form.

Stirrups of inch by No. 14 metal bars anchor the rods securely in the concrete. Three 1½-inch reinforcing rods 66 feet long are used to reinforce the top of the girder. In addition to the roof load the girders have to carry a 16-feet gallery on each side of the building which is 150 feet long. In designing these girders provision was made also for suspended tracks for a light travelling crane. Cross beams are provided between the girders dividing the roof into square panels. These beams are 11 by 6 inches in section and are reinforced by four ⅞-inch rods. The reinforcement of the roof slabs consists of ⅜-inch rods 5-inch centres running in both directions.

The G.W. Railway stores at Royal Oak Station, Paddington, are designed to carry a safe load of 5 cwt. per foot superficial. The clear span of the beams between the supporting columns is 23 feet; the beams are 2½ feet in depth, including the thickness of the floor, and 1½ foot in thickness. Incorporated into these beams, and at right angles to them, are smaller beams 1 foot 10 inches deep and 1 foot thick, and spaced at 5 feet centres. The floor is 5½ inches in thickness. The reinforcement is on the Hennibique system, consisting partly of trussed and partly of straight and vertical rods.

A rough and ready method of ascertaining suitable dimensions for beams to carry moderate loads, if properly reinforced, is an inch in depth for each foot of clear span, and the width one-half the depth.

In constructing compound floors, or floors and beams combined, it is not advisable to form the beams first and the floor on top of the beams. Both should be concreted at the same time, as the strength of the beam is in that case measured from the floor concrete level, as Fig. 91. In filling the troughs and forming the floor it is essential that the disposal of the concrete should not be suspended at any point between the supporting walls or columns, and that the concreting generally should be carried on as rapidly as possible. The weak points in concrete floors

and beams of any description are where the work has been suspended for a time. When this is the case it has been suggested that the surface, or sides, or ends of the concrete, whichever it may be that a new portion is to be joined to, should be hacked with a pointed tool, but in doing this it sometimes happens that the concrete immediately below the surface, not having acquired the same hardness as the top, is loosened as well, and more harm than good is the result. My opinion is that throwing some thick neat cement grout over the surface forms the best connecting medium.

One of the advantages of reinforcement is that it remedies to a great extent the fine cracks which are so often a disfigurement to concrete floors and walls. For this reason I employed iron hoop in my first experience, but round rods are better.

Colonel Wynn, R.E., says that the tendency of concrete to crack without reinforcement is ten times as much as if reinforced. This must, however, depend on the amount of exposure to climatic influence, but reinforcement no doubt very largely prevents evidence of contraction and expansion.

The greatest stress on beams is over column supports, and to alleviate this somewhat it is usual to embed additional rods extending a short distance each side as shown by Fig. 92.

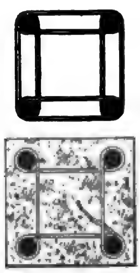
Where beams are rigidly pinned into walls, a certain portion of their length is acting as a cantilever, and their upper surfaces undergoing a tensile instead of a compressive stress, but which gradually diminishes the farther the beams recede from the wall, and, like floors, they are as a result capable of supporting a heavier stress than if the ends were free. Beams over intermediate columns are similarly affected, a reason for making them continuous if practicable.

Where the beams are of considerable length and supported at intervals by columns, the tension rods where

they join over the column supports should, if possible, be connected to form continuity throughout, and the reinforcement of transverse beams connected to that of the longitudinals as well.

The strength of the beams is increased also if the concrete of the reinforced column is spread out at top, as shown by Fig. 92. This reduces the flexure of the beams as well, and the projecting concrete can be used as a core for plaster caps, if any are required.

But unlike most other systems of construction there would appear to be no absolute certainty at the present time of determining the strength of reinforced concrete



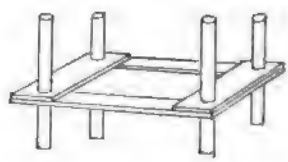


FIG. 94.

Bonds or Ties for Reinforced Columns.

Hennibique's Bond or Tie.

floors and beams without actual experiments with the same class of materials, and the work performed by the same class of workmen under similar conditions, without allowing a very ample margin for contingencies.

The reinforcement of concrete columns consists usually in embedding steel rods or bars vertically therein from the bottom of the column to the top. Usually four, one at each corner, are employed, but this rule varies with the height of the column, the load it has to carry, the size of the columns, the quality of the concrete, and other conditions, so that mathematical calculations as to the amount of reinforcement necessary must be taken with a good

deal of reservation. The vertical rods or bars are kept in position and rigidly connected with rods, hoops, or small bars. Where the vertical rods go through bonds or ties of flat steel bars there is less difficulty in keeping the former in position—always a trouble when the concrete is being deposited in place.

Fig. 94 shows two forms of bonds. My view of a suitable form of reinforcement for columns is as shown by Fig. 95, which consists of light angles about $1\frac{1}{4}$ in. by $1\frac{1}{4}$ in. by $\frac{1}{8}$ in., or $1\frac{1}{4}$ in. by $1\frac{1}{4}$ in. by $\frac{1}{4}$ in., with bonds formed of $1\frac{1}{2}$-in. by $\frac{1}{8}$-in. hoops riveted thereto about 12 to 18 in. apart.

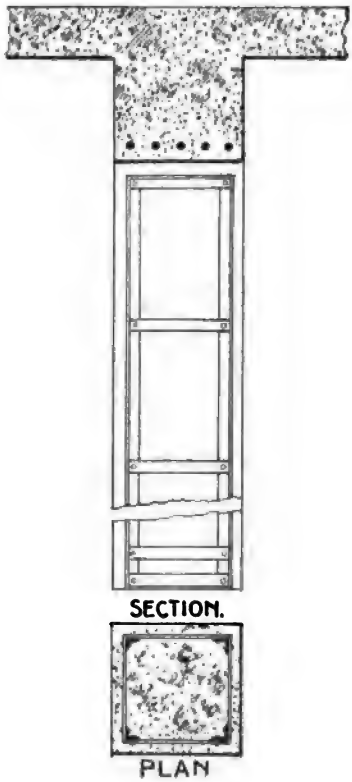


FIG. 95.
Suggested Form of Bond or Tie.

It is usual to let the reinforcement standards rest on a plate of iron about $\frac{1}{4}$ inch in thickness, and of the same area as the column, or larger if considered necessary, and, it is almost unnecessary to add, on a very solid foundation.

The size of concrete columns must be judged by circumstances; we know that a common class of concrete, composed of coke breeze six parts and cement one part as tested by Messrs Kirkaldy, bore nearly three times the compressive strength of stock brickwork in mortar, *i.e.*, 131 tons to a foot superficial, and Mr Grant found that Thames ballast eight parts and cement one part, crushed

with 54 tons to a foot superficial, and Portland stone chippings eight to one, made concrete which failed with 132 tons to a foot. The strength of ordinary concrete under compression is therefore so enormous, and which can be increased by using a larger proportion of cement, that it is a question whether the reinforcement of concrete columns for ordinary loads is a necessity at all times. In high columns the first symptoms of weakness would be in buckling or bending, and in such cases the reinforcement would be of great service, but with short columns of fair size buckling would scarcely take place previous to failure by compression. The general rule is that for reinforced columns to support heavy loads their least diameter should be one-twelfth their height, that is, a column 12 feet high should be 12 inches square, or if taper, 12 inches square at the top. The bonds or ties may be any distance apart considered necessary, but usually taken as equal to the diameter, that is, for columns 12 inches square they should be 12 inches apart. Possibly this admits of a considerable increase, but the size of the columns, amount of reinforcement, and quality of concrete must be guided by the load they have to support.

The proper proportion of aggregate and matrice varies with the character of the aggregate, but one to seven should be good enough for almost any purpose, but increasing the proportion of the matrice has a marked effect on the strength of the concrete.

Professor Talbot made a series of experiments at the Watertown Arsenal for the United States Government, on concrete columns, plain and reinforced. The columns were 12 feet in height, and the concrete about one to two and three-quarters. The reinforcement was 4—¾ rods fixed vertically with no ties or bonds. The result was as follows:—

Kind.	Age in Days.	Crushed at lbs. per Superficial Inch
Plain	69	1,710
"	65	1,610
"	61	1,709
Reinforced	65	1,850
"	65	1,936

This appears to prove that vertical rods without bond ties are almost useless, and that for walls they effect no object unless well bonded together.

The U.S.A. Government tests showed that concrete for columns one to five not reinforced was only one-fifth the strength of one to one, and one to three one-half the strength of one to one, and where reinforcement was practised (quoted by Mr Reid in his book), the result was as follows:—No reinforcement, 1,413 lbs. per square inch; with thirteen hoops or bands, 2,232 per square inch; with twenty-five hoops or bands, 3,428 per square inch; with forty-seven hoops or bands, 5,289 per square inch.

This is evidence that where very heavy loads have to be carried reinforcement greatly increases the strength of concrete columns. But the quality of the aggregate and matrice, climatic conditions, and the care, or want of care, displayed in the application of the concrete, are all factors in the result, and it becomes necessary therefore to allow for a greater margin of strength than is estimated for to be on the safe side.

For purposes where constructional materials are subject to climatic influence the great advantage of concrete of requiring no periodical painting—as for instance in bridge beams and trusses and exposed steel work generally, is very apparent, for not only is deterioration of the metal from oxidation prevented but the strength as a result is maintained for an indefinite period.

Per contra, if a sudden unusual strain should at any time occur to the constructional members, the effect on the skeleton steel work cannot be ascertained, nor if signs of

weakness are apparent can more than a superficial examination take place. These remarks apply more especially to exposed structures such as bridges and the like, subject to sudden stresses, and in a minor degree to external and internal beams and lintels of new buildings.

In many instances the steel work is of a constructive character, intended to alone carry the load, but encased in concrete to protect the steel from oxidation, and although the latter may derive some assistance from the rigidity it conveys, the dead load is increased to the extent of the weight of the concrete.

The object is not only to prevent oxidation but as a protection from fire, the two great drawbacks to the use of constructive steel, and in this respect it well fulfils its object. Work of this description can scarcely be called reinforced concrete or ferro-concrete, but may be more aptly described as concrete-steel construction.

Experience of this class of work is comparatively of so brief a character that there are doubts in some scientists' minds as to whether reinforced concrete and concrete-steel under trying circumstances are quite up to the standard of our expectations. Our descendants in a hundred years' time will be in a better position to judge of this. There are other forces to consider beside oxidation—electricity for instance, and in connection therewith the question has been raised whether, under certain conditions, where steel is hidden in or buried by concrete—in towns more especially where electricity is developed for so many purposes—electrolysis might not occur and corrosion follow as the result. In a paper read before the American Institute of Electrical Engineers, Mr A. A. Knudson said that he had made experiments in this direction. "In March 1903, blocks of concrete containing iron tubes were prepared for the purpose. These blocks or samples were made of equal parts of Portland cement and sand, in ordinary metal pails, slightly larger at the top than at the bottom. In the centre of each block was placed a 2-inch wrought-iron pipe. Pre-

liminary tests were made with the object of selecting such amount of current for the series as seemed advisable. From the information obtained, it was decided to commence a series of tests extending over a time of thirty days with the three blocks immersed, and under the following conditions:— One block was immersed in fresh water and another in sea water. These were connected in series, with 0.1 ampere continuously flowing through them. A third block was immersed in sea water, but no current was sent through it. This was for the purpose of comparison after the blocks were broken open. These tests, which were conducted at the Electrical Testing Laboratories, New York City, were begun on 1st February 1906, and ended 2nd March 1906. The results of importance on this first group of blocks were found in the gradual disruption of the concrete, as shown by cracks as time went on, and the appearance of electrolysis and loss in weight of the iron tubes of both No. 1 and No. 2 when the tests were concluded. No. 3 showed a perfectly clean and hard interior surface, and there was no evidence of corrosion. It was like breaking open a piece of granite, and required the services of a man with a sledge-hammer and chisel. The other blocks under test could be prised apart with an ordinary screwdriver inserted in the cracks.

"The result of these experiments seemed so important that it was thought best, before drawing conclusions, to have the tests repeated, and therefore another set of experiments similar to the first was made, to see how the data would compare. The result of this second series of tests only confirmed the results obtained in the first instance.

"The object of using sea water in the tests, as well as fresh water, was to ascertain and compare the resistances shown in the curve sheet, and also to conform as nearly as possible to conditions found in practice, such as bridge piers and other structures that are located on water fronts.

"These tests and experiments go to show that only a small fraction of an ampere is necessary to cause electrolytic

action. It is only necessary, where electric currents are present of sufficient voltage in the proper direction, to cause even a very small amount of current to pass that will in time cause corrosion on interior steel structures, whether placed in concrete, in brickwork, or in granite masonry. It is not expected, however, that large granite piers would develop cracks, but electrolysis to interior steel work and to bridge anchorages may go on just the same."

A distinction must be made between reinforced concrete walls and skeleton steel construction in which concrete may be used as a backing to or a filling between steel stanchions, and with a brick or stone facing, in which case the concrete is of a secondary character. The latest adaptation of reinforced concrete is for the purpose of increasing the strength of ordinary concrete walls, or concrete walls faced with other materials.

Reinforcement for concrete walls other than piers, buttresses, and counterforts consists of vertical, transverse, and lateral rods, hoops, or bars, built in as the work progresses, either in combination or otherwise as thought necessary. External walls of buildings must of necessity be of considerable thickness to provide for reveals of doors and windows, and provide a sufficient bearing or support for floors, &c., and as concrete of an ordinary character is very much stronger than the best brick wall, and external walls are in most buildings tied together by the floors at intervals, steel reinforcement, as a rule, is much less a necessity than for floors and beams. The crushing strength of ordinary concrete is as proved about three times that of the best stock brickwork in lias lime mortar, and which can be increased if desired by the use of selected aggregates and a greater proportion of cement.

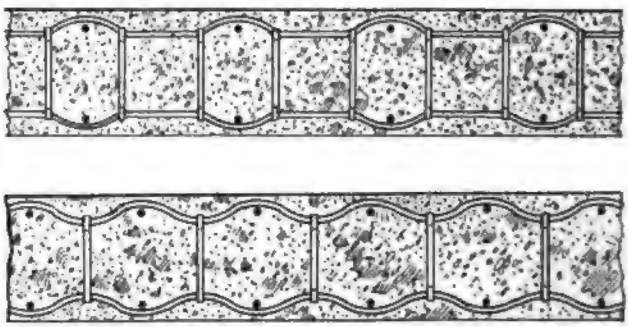
The walls being tied together at intervals by the floors and internal division walls, could not readily buckle or bend, unless subject to enormous stress, or were unreasonably thin in proportion to their height and the load they had to support. Transverse ties are only wanted as a tie

or bond for the concrete and may be of use if the aggregate is small and uniform in size, but if it ranges from the size of coarse sand to that which would but just pass a 2-inch or a 2½-inch ring, and in suitable proportions, no better bond could be obtained, and auxiliary help for bond ties is practically unnecessary. Figs. 96 and 97 show suitable forms of lateral, vertical, and transverse ties. Lateral reinforcement is, apparently, only required where the foundations are not of the best or as a factor in combination with the vertical and transverse reinforcements. Iron hoop bond for brick walls, used laterally, was in common use fifty years ago but appears to be now discarded. If it was found unnecessary for brick walls, why is it needed for concrete walls where the bond is—or should be—perfect without reinforcement? A practical illustration of this takes place when a concrete wall has to be removed; sledge-hammers and steel wedges are the only tools to deal therewith; it is a useless effort to endeavour—even with these—to split it into two thicknesses. In my own experience the time required to cut a rough opening in a 12-inch wall 1 to 7 for a doorway 7 by 3 feet, the concrete being of crushed bricks, was two and a half days each for two labourers. If concrete walls become general in London, future housebreakers will have to devise some new method for razing them.

I know of no more convincing proof of the extraordinary strength of concrete wall construction, than to witness the attempt to demolish, say, a 12-inch concrete wall that has been built for two years at least. Results by figures do not convey a correct impression; we may form some general idea by witnessing the breaking up of concrete foundations of roadways for pipes, &c., often to be seen in London streets.

Vertical rods in walls are of various sizes, and built in at certain distances apart, as may be considered necessary. They are arranged to tie or bond to the longitudinal reinforcements, and the latter to be

connected to the transverse ties, and which together admit of numerous forms of combination, as shown by Figs. 96 and 97. Lateral reinforcement is, however, a valuable factor in concrete walls in preventing evidence of change of form through climatic influence, and for this reason should always be employed. For this purpose I formerly used iron hoop, as it can be obtained in longer lengths than rods or bars, two or three to a course and about each 2 feet in height of the walls; round bars or rods are better in a general way. The former practice of tarring and sanding or painting hoops used for brick-



FIGS. 96 AND 97.—Plan of Wall Ties.

work bond is quite unnecessary for concrete walls. Over window, door, and other openings, if no lintels are used, a larger number of hoops or rods are necessary and which should be 3 to 4 feet longer than the openings and bent up or down at the ends to give a key to the concrete.

Considering the enormous amount of money spent every year on Government buildings, it is unfortunate that no steps have been taken to thoroughly investigate the use of concrete. A question was asked in the House of Commons lately, as to the adoption of a foreign patent floor system in a certain Government building. The reply

was not, as one would expect, that it was the best for the purpose, but that it was the cheapest, and no other reason was vouchsafed. The opinion of the members, and the Speaker too, apparently, was, that except as regards price, concrete floors were identical all the world over.

It is unfortunate, but the general opinion seems to be that the application of concrete is so simple a matter that its use as a speciality, and the employment of workmen, foremen, and others who have had experience therewith is quite unnecessary, and this is one reason why, in America a much better knowledge of the subject prevails, owing to it being recognised that the opinion held in this country is altogether wrong.

But no amount of theory or descriptive writing can take the place of practical experience, nor must we be led away by too enthusiastic disciples of concrete construction.

Under any circumstances it is very desirable to ascertain results from actual trials under varying conditions. Reinforced concrete has of late years received a good deal of attention, and there can be no doubt it is destined to become one of the main factors in building construction.

Mr Homer A. Reid, an American engineer, says in his book on "Reinforced Concrete": "Concrete should be used with the same care and judgment that has made older and other kinds of construction both safe and satisfactory. It should be remembered that there are other and tried kinds of construction which are much more suitable for use in many situations. Under such conditions enthusiasm for a given form of construction should be tempered with good judgment, and the most suitable material chosen."

Unfortunately, in this country there is no official authority to render help or assistance in furthering the development of new forms of construction. Everything in that direction is left to private enterprise, and to patentees of various processes whose main object is to make money, and as a result some of the best known and most extensively used systems are the outcome of well-filled purses.

The Government of the United States has done, and is still doing much with the object of developing the use of concrete by means of experiments and appliances for testing its properties and capabilities in every possible way, and publishing the results for the public benefit, so that its use there is far in advance of this country.

CHAPTER XIII.

FORMS AND FALSE WORK.

WHATEVER form of reinforcement is adopted for beams, floors, &c., certain principles of construction in connection with the preliminary work are necessary. Wood troughs in which the concrete is to be deposited for beams and columns, and platforms or centering to support the concrete for ordinary floors and other purposes are required. For this work each practitioner apparently has invented his own name—panels, casings, shuttering, centerings, platforms, &c., but in America one general name applies—"false work," and the various portions are called "forms," because they form the supports for keeping the concrete in position until it has set.

Concrete takes away much of the carpenter's trade by dispensing with wood beams, joists, and floor boards; but in many instances it is more than made up by the large amount of labour and materials necessary for false work, more especially where beams are numerous. Where no reinforced beams are required, or steel beams are employed, the false work for the actual floor is much simplified; the under side is straight throughout, and it is an easy matter to arrange the false work necessary to support the concrete, either by props beneath or suspended by bolts attached to timbers over; but it is often the case that the concrete is not of the same thickness as the joists are in depth, so they have to be stilted with concrete, as shown by Fig. 98. As thinner concrete for floors than formerly is becoming general, stilting is usually adopted

where main steel beams are employed a considerable distance apart, and small transverse joists are attached thereto to support the concrete, iron angle bearers riveted to the beams being general at one time, as Fig. 99, but stilting is preferable. It costs less; it is a protection in case of fire; it assists to stiffen the beams and to strengthen them, and reduces their flexure. With a view to protecting the bottom flanges of steel beams it is sometimes specified that they shall be encased with 1 inch or 2 inches in thickness of concrete, as Fig. 100. With the forms for the stilting in position, this is somewhat difficult; the concrete is simply pushed under with a piece of iron or wood crooked at one end. When the forms are released, portions of the concrete often come away with them, and the flanges of the beams are visible, the result being that the bare places are at the first opportunity filled up with a dab of mortar; sometimes coarse grout is run under the flanges. It is doubtful whether the flanges are efficiently protected in this way, and whether a wrapping of expanded metal lathing round the bottom flanges and tucked into the concrete on each side, as Fig. 101, and plastered with lime and hair mortar, is not very much better. Sometimes steel wires are bent in the form of a stirrup and embedded in the concrete under the flanges, and their ends anchored in the concrete stiltings.

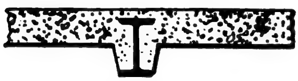
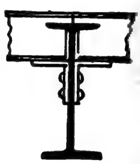


Fig. 98.—Stilted Floor Joists.



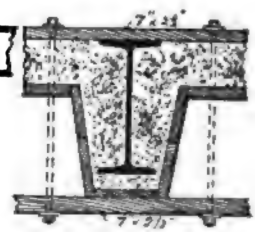


Fig. 99. Fig. 100.

Beam Form.

This is a difficult thing to accomplish, and is very seldom satisfactory.

Sir M. Shaw, when Chief of the London Fire Brigade, said if only an inch of plastering mortar could be made to stay on all exposed portions of steel beams, the danger from fire through their collapse would be largely minimised.

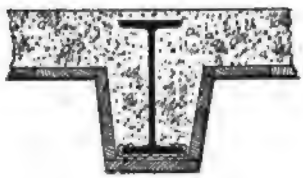


FIG. 101.—Encasing the Bottom Flanges with Lathing.

Forms for floors are usually kept in place by bolts attached to wood battens resting on the top of the beams, and to others below, as Fig. 102. Evidence of the trouble that so—apparently—a trivial matter as temporary arrangements to keep the concrete in place until it is set, is to be

FIG. 102.—Forms for Flat Floors.

found in the fact that more than two dozen patents have already been taken out with this object alone.

After experimenting in various directions for the same

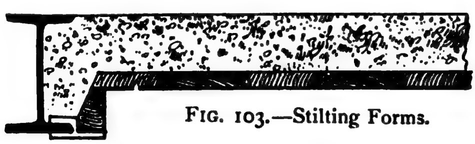


FIG. 103.—Stilting Forms.

purpose, I have adopted and patented some very simple methods, Figs. 103 to 105.

Fig. 103 consists of tee iron clips about 3 inches in length, the webs bent so to wedge them on the bottom

flanges of the beams. Stilting pieces of wood of the depth required bear on the flange of the clip, a few small wedges if necessary being used between the wood and the clip which, when removed, enable the stilting form to be released.

Fig. 104 is adapted for floors where the concrete is flush

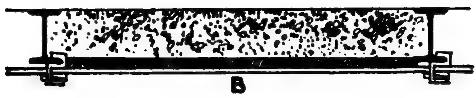


FIG. 104.—Form for Flat Floors.

or fair with the bottom flanges of the joists, and the latter are any distance not more than 6 feet apart. Clip hangers made out of steel bars about 1 by $\frac{1}{8}$ inch have a mortise, through which iron bars B, about $1\frac{1}{4}$ by $\frac{1}{4}$ inch, are passed; the bars are fixed 3 to 4 feet apart, and inch, or thicker if necessary, boards are laid on them to uphold

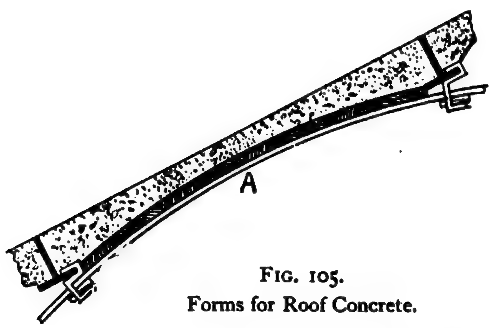


FIG. 105.
Forms for Roof Concrete.

the concrete. The clips are driven on lightly with a hammer. The small wedges are to allow the bar B to be loosened and withdrawn, the boards liberated, and the clips removed.

The same principle is adapted for roofs where purlins support the concrete, A, Fig. 105, being the bar. The object of curving the concrete is to lessen the amount and weight without reducing the strength.

Fig. 106 shows an arrangement of forms necessary for beams and floors. The posts should rest on a board or plank at bottom, and placed as far apart as may be considered advisable. A pair of wedges under each post at bottom is necessary, and when released and the 2 by 2 inch wedges withdrawn the whole of the timber work comes away.

It is sometimes the practice to construct reinforced concrete beams first, remove the beam forms, and erect the floor forms and do the floor concrete as a subsequent process. But this is altogether wrong, as much longer time is required, and the floor having to be formed on top of the beams the latter are deeper than necessary, and possess no additional strength. Where concrete beams are not constructed *in situ*, this arrangement is, however, unavoidable.

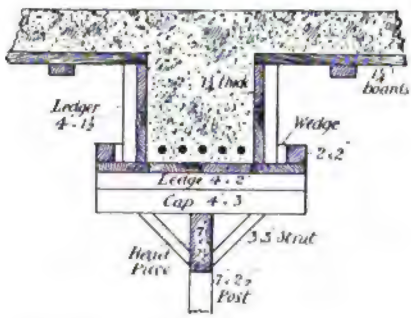


FIG. 106.
Forms for Beams and Floors Combined.

Forms for concrete columns should be of a substantial character, or, if of light construction well and rigidly bound together—for, like water, concrete exercises pressure on all sides. Practitioners differ a good deal in their methods of making forms for columns. My own view for economy and simplicity is shown by Figs. 107 and 108, which are horizontal sections of column forms. The sides A A are 1½ inch in thickness and strongly ledged together at intervals to prevent the wet concrete from warping and twisting them; they should be wrought and thicknessed, and reach the full height of the column. B B are wood strips or fillets about 2 inches by 1 inch firmly nailed to A, the full height of the form and each in one piece. C C are boards dropped

in singly, as the concrete is being deposited in place. D D are light wood clamps correctly made to keep the sides A A in position.

Necessarily the forms require to be strongly stayed to prevent any divergence from the perpendicular. This arrangement can be applied to the encasing of steel stanchions, with wire bonds embedded in the concrete, as shown by horizontal section, Fig. 108.

The sides A A must be watched for alignment; there is no remedy whatever if they once get out of position and any portion of the concrete has been deposited in place. D D are light wood clamps, made so to require no wedges. When the concrete is hard the clamps D D are easily

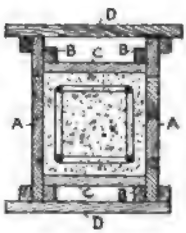


FIG. 107.

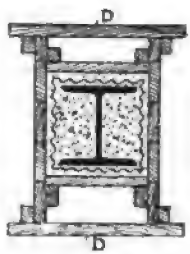


FIG. 108.

Plans of Column Forms.

knocked off with a hammer, which releases the form. The woodwork should then be at once cleaned, and is ready for re-use for another column. The principle can be applied to any form or shape column, and to steel stanchions, and if corrugated iron bond ties are inserted in the concrete at intervals there is no better way I know of to protect the latter from fire.

A practical foreman carpenter should be capable of devising his own forms to suit the numerous requirements of reinforced concrete construction, and possibly better in some instances than cut and dried rules and instructions. Obviously some experience in this direction is an advantage.

Care should be exercised in ascertaining that the inside

of all forms is clear of chips, sawdust, and débris, and in the case of column forms it is well to have a loose board at bottom to enable these to be cleared out before the concreting is commenced.

The timber used for forms requires to be of various sizes and degrees of strength, according to the nature of the work and the load to be supported. The boards should not be too dry, or the wet concrete may cause them to swell and buckle out of shape. They are better, too, if thicknessed, so that when removed ridges in the concrete are not in evidence, which is sure to be the case otherwise. When the troughs or floor supports are struck, the boards should be at once carefully cleaned with a scraper or stiff broom of the cement that may adhere to them; if this is not done it will afford a key for the cement when they are re-used, and probably pull away some portion of the concrete and leave the surface of the latter anything but smooth, leading those who are unacquainted with the cause to believe that the rough appearance is the result of the concrete not being well mixed. It is sometimes usual to make holes ¼ inch diameter in the forms at intervals, to allow the water not wanted for hydration to pass away. The water should be quite clear, and will be found to possess an alkaline taste. If any cement oozes through the boards with the water it is evidence that too much has been used in mixing the concrete.

The boards should be reversed each time of use as far as practicable, to prevent them from twisting, warping, or buckling. This is easy enough for floor supports, but not so where the boards have to be ledged, as for deep beams, and this points to the necessity of dispensing with ledging where possible. After the boards have been used for three or four times in succession, and at short intervals, they will be appreciably weaker as the result of being sodden with water; if dried in the wind and exposed on both sides until they are quite dry again, their normal strength will be in a great measure restored. Boards about

7 inches wide or less are cheapest and most convenient to handle, and less liable to warp or twist than wider ones. It must not be expected that boards which have been used for forms are of much value for other purposes when they have fulfilled their object; they are impregnated with cement and grit, and find no favour with carpenters who have to convert them to other uses, except for rough fencing, hoardings, &c. To prevent the cement adhering to the forms, oiling the surfaces, or a coat of soft soap of the consistency of cream, or paraffin, or a non-drying oil and paraffin mixed, is sometimes applied; a coat of thick lime wash is economical and effectual. Where special work requires the concrete to be left as smooth as possible, the troughs or moulds can have paper or coarse thin canvas laid on or against the wood; the paper adheres to the concrete, and is easily removed with water when the forms are taken away.

The forms should be so constructed as to be easily removed without hammering and jarring, which tend to loosen the surface of the concrete when the latter is in a comparative soft state, and they should not be too clumsy or unmanageable. For floors, 1 inch thick is best, or 1¼ inch if the amount of concrete is considerable, and as a result heavy, and the bearers spaced not more than 4 feet apart.

How long the forms or temporary boards for upholding floors should remain before removal depends entirely upon circumstances. In dry warm weather, if the joists or walls upon which the concrete rests are not more than 5 or 6 feet apart, three or four days are sufficient. In my own experience, where they have been 9 or 10 feet apart, seven days has been found sufficient, but ten days is better. In cold or wet weather these intervals of time should be increased 50 per cent.; never accept the result of examining the surface of concrete floors, and because it is hard assume it is in a like condition throughout; it never is, nor approaching thereto, owing to the atmosphere not being able to penetrate freely.

In frosty weather the concrete sets very slowly, if at all; this must be taken into account in calculating the time allowed for striking the forms. Beam forms require to be kept in position longer than those for floors—never less than two weeks in summer and longer in winter, if time permits. Column forms can be dispensed with in three or four days usually; this again depends on their height and if they have more than their own weight to carry for the time being, and until they have acquired some strength.

CHAPTER XIV.

Concrete as a Fire-Resisting Material.

It was the opinion at one time that if floors and other parts of buildings were incombustible the buildings themselves were fireproof. Their behaviour when exposed to intense heat on one side and the application of water on the other was not taken into account. For many years the bottom flanges of iron joists and beams were left unprotected, or at most covered with a thin coat of plaster, and sometimes with wood. Steel and iron joists would, in a large fire under such conditions, attain a high temperature in a short time ; the heavy weight would cause them to bend, and the lower half of the concrete floor, already weakened by heat, would as a result be subject to an increased tensile strain. The heat would render the bottom flanges weak at the time when the strain was greatest, and a general collapse was often the result, causing fireproof floors in their early days to be avoided in buildings on fire. Another cause was that the expansion and subsequent contraction of the concrete mass, if the floor was in inseparable sections, each of many superficial feet, would probably part at its weakest places through the heat causing it first to expand and as it cooled contract.

What it amounts to is that to render floors, roofs, and other parts of buildings fire-resisting, every portion of steel or other metal construction must be encased in or covered with some material that will resist heat without breaking up, as far as practicable, and is also a bad conductor.

Fire-clay or pottery clay will effect the purpose to a great extent if some way is adopted to afford means of expansion and contraction. With this view I have used shields for steel joists about 12 inches in length (Fig. 109), made of pottery clay, either in two pieces or in one piece. In the latter case they have to be put on the joists before the latter are fixed in place. A coat of ordinary plastering mortar is an excellent protection against fire, but metal lathing must be used, and if air spaces are arranged between the steel joists and the ceiling the protection is largely increased.

With regard to aggregates for resisting heat, there is no doubt that those which have passed through fire are

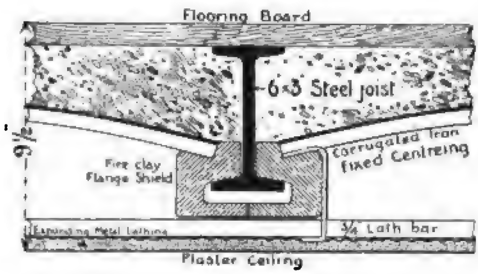


FIG. 109.—Flange Shield.

the best. Even these are unable to withstand the strain arising from expansion and contraction when a large fire occurs, but tests made by the Fire Protection Committee proved that they were capable of doing so to a considerable extent. Valuable as these tests are they were only possible on a small scale, but were prepared with the greatest care, very different to the way in which floors are usually constructed. Strange to say coke breeze, which has never been considered a superior material for fireproof construction, proved to be one of the best, although it is a common occurrence still to forbid its use as an aggregate. This result was, however, anticipated by Mr J. J. Webster, M.I.C.E., in a paper on fireproof construction read before

the Institute of Civil Engineers about twenty-five years since. Mr Webster made a number of experiments with a view of finding the best aggregates to resist fire, and the average results were as follows. The proportion used was one of cement to four of an aggregate.

Material.	Breaking Weight per sq. in. at 60 Deg. Fahr.	Breaking Weight per sq. in. after being heated and quenched.
Neat Portland cement - - -	554.6	117.2
1 part cement, 1 part sand - -	448.0	93.0
" 3 parts sand - -	100.8	18.7
" 5 " " - -	74.6	15.0
" 4 " iron furnace slag	108.1	23.06
" 4 " broken fire-brick	84.4	30.5
" 4 " pumice stone -	94.58	38.3
" 4 " coke breeze -	69.9	39.06

Possibly the sand was Thames sand, and the experiment proves it to be a bad material to stand fire.

As will be seen, neat cement and cement mixed with one, three, and five parts of sand respectively; and slag one to four, lost approximately 80 per cent. of their original strength, and broken fire-brick 60, while coke breeze came out best of all with about 40 per cent. loss.

The result is somewhat alarming, and the description of "fireproof" apparently a misnomer, but it points to the necessity, where cost permits, of a hanging plaster ceiling as a first protection in case of fire.

This is another instance of the folly of taking matters connected with concrete on trust, and *per contra*, the value of making actual trials with various materials. Most people would, as a matter of course, place broken fire-brick, pumice stone, and slag far above coke breeze for strength and fire resistance, instead of which the opposite was proved to be the case.

Professor Bauschenger, of Munich, tested concrete pillars after repeatedly heating them to a red heat and quenching

them with water, and reported: "Of all materials tested, Portland cement concrete stood fire the best, and ordinary and clinker bricks laid in Portland cement mortar almost equally as well."

At a large fire at Messrs Waterlow & Sons' new buildings, Hill Street, Finsbury, in 1871, the effect was described by Mr Arthur Cates, the architect, at the General Conference held in London in June 1878, as follows:—

"The iron doors, columns, girders, floors, and roof, and all the ordinary stonework were destroyed, and even the granite paving of the courtyard was damaged. York landings 3 feet by 8 feet and 6 inches thick, forming the sills *under* the iron doors, were entirely destroyed, while the concrete lintels *above*, which had been exposed to a much fiercer heat, were quite unhurt."

The result of this fire was that in Messrs Waterlow's newly erected buildings all the floors and many other portions were made of concrete of a similar character, and all iron girders and columns were encased with it.

Mr Alexander Payne, an architect of London, at the same meeting, said:—

"I might mention a case in which concrete has been used in connection with iron and exposed to great heat. About three years ago I had to carry out a manufactory at Oldham in Lancashire, in which there were several large drying floors. The flues from these were brought to one end of the building, and there collected into a chamber lined with fire-brick, from which one large main flue passed to the chimney. This chamber was covered with a dome of Portland cement concrete, and wrought-iron ring ties bedded in it to prevent the thrust. This was an instance of Portland cement concrete exposed to great heat, and with iron embedded in it. I have written to the secretary of the company for whom this manufactory was built, to ask if the concrete cover or dome had ever cracked, or shown any weakness from the effects of the heat, and he has sent me the following reply from the manager of the works:—

"'The underground flues are level until they meet the main flue just outside the end wall. At this junction they are covered by a concrete dome, with a stone slab 3 inches thick on top. Although the heat at this point must be immense at times, I have never seen any signs of the concrete cracking.'"

The point is will fire-clay or pot-clay blocks, lintels, and tiles resist fire better than concrete? Solid blocks or bricks would do so undoubtedly, although they might expand sufficient to push out the walls, but their weight is prohibitive. Hollow blocks are necessarily weak in compression compared with solid ones, and according to the official and other reports relative to their behaviour in the large fires at Baltimore, Rochester, and San Francisco a few years since, they were mostly a failure. The *Builder* for 30th April 1904 says:—

"Property to the value of over £500,000 was destroyed in a conflagration at Rochester, U.S.A., towards the end of February, and technical details regarding this fire have now come to hand. It is interesting to observe that, as in the case of the Baltimore fire, the terra-cotta or tile floors were again seriously damaged by losing their lower—and to a considerable extent their vertical—webs. Although the tile arches in the so-called 'granite building' have not fallen, they will practically one and all have to be reconstructed owing to loss of strength. As in the case of Baltimore, the tile work did not even have the extra strain of the application of cold water, which, if applied to heated tiles, leads to cracking and to a considerable amount of disintegration. To quote the official report of the United States Government engineer on the Baltimore fire, whose opinion is again borne out at Rochester: 'Hollow terra-cotta suffers a large percentage of loss in its commercial forms owing to mechanical failure under stresses due to expansion of construction,' and this opinion should be compared with another portion of the same official report which states in respect to concrete that 'the efficiency of

concrete on the whole is high, and is preferable to commercial hollow tiles for both floor arches or slabs, and column and girder coverings.' After that official dictum it is unlikely that any more Government and municipal work in the United States will show terra-cotta floor construction, and the sooner this example is followed in England the better, in all probability, for the general public."

The actual cause of the failure of hollow block floors, according to the United States Government engineer, was that the blocks were skinned down to a minimum thickness, the webs being rarely more than $\frac{5}{8}$ inch thick. When exposed to the fire these soon got red hot; the rest of the tile, being surrounded by dead air spaces, remained cool; the change in temperature near the junction of exposed and non-exposed webs was so rapid that stresses were set up exceeding the strength of the material, and the exposed web drops off. If it does not do this under the heat alone, a stream of water from the nozzle of a fire hose quickly brings about the same result. If the material in the webs were made thicker, so that entire variations in temperature would occur within the thickness of the exposed web, these stresses would not exist, and a steel frame so covered would be able to resist many fires with no loss to itself worthy of note. He advises $1\frac{1}{2}$ inch of *porous* terra-cotta as the minimum.

A writer in *Concrete* for November 1906, says:—

"For certain purposes the porous terra-cotta lintel may be useful and economical, but generally speaking concrete is found to be more practical and constructionally more sound, and all things considered less costly. As for dense terra-cotta for floor construction, or the protection of metal work, its application is scientifically and practically wrong; in fact terra-cotta is distinctly dangerous from the fire point of view. The complete disappearance of dense terra-cotta in floors and protective coverings intended to be fire resisting is only a matter of time."

The expressions "porous" terra-cotta and "dense" terra-cotta apply, the latter to the material used for building purposes in the ordinary way, and the former to terra-cotta or common fire-clay in which sawdust, shavings, charcoal, tree bark, or other combustible materials in a fragmentary state are mixed, and which being consumed at the time the blocks are being burnt in the kilns renders them porous. The practice, known in this country many years ago, was introduced to enable nails to be driven therein for the fixing of joinery or timber work. It is commonly supposed to be an American invention, by reason of having been so largely adopted there for floors, &c. On the other hand, although concrete will stand a severe fire without collapsing, there can be no doubt that exposure to high temperature tends to weaken it considerably, and when this occurs both concrete walls and floors should be tested before they are passed as safe. The erection of enormous smoke shafts with concrete is an American invention, and is an experiment worth watching. In my own experience smoke flues of chimneys of ordinary dwellings, where constructed of flint or river gravel concrete, usually give evidence when swept of some dislodgment of surface concrete, and these high chimneys are said to be made of concrete composed of Portland cement and Thames sand, the latter being mainly the detritus arising from flint strata in the chalk formation.

Although many experiments have been made from time to time with concrete composed of different materials, no exhaustive trials with various kinds of concrete, tested under exactly similar conditions to ascertain what will best resist fire, have been made until a year or two since, when the British Fire Prevention Committee issued a report of the experiments made by that body, and which is free from all taint of partisanship. The tests were made in this way. The trial floor was divided into seven equal bays; the size of each bay was about 10 feet by 2 feet 7 inches, the thickness of concrete 5½ inches. To support

the floor there were six rolled steel joists 6 by 4½ inches, the ends being built into brick walls and a clear space of an inch being allowed at each end of the joists to provide for expansion. There was also a similar clear space lengthwise between each of the seven slabs. The steel joists were encased in concrete. The component parts of the concrete floors were as follows:—

No. 1. Furnace slag from Thrapston to pass a 1½-inch ring three parts; clean pit sand from Kent two parts; Portland cement one part.

No. 2. Broken bricks to pass a 1½-inch ring three parts; pit sand from Kent two parts; Portland cement one part.

No. 3. Broken Guernsey granite to pass a ¾-inch ring three parts; clean pit sand from Kent two parts; Portland cement one part.

No. 4. Burnt ballast broken to pass a 1½-inch ring five parts; Portland cement one part.

No. 5. Coke breeze to pass a 1½-inch ring free from fine dust, five parts; Portland cement one part.

No. 6. Furnace clinker from the furnaces of large boilers to pass a 1½-inch ring three parts; clean pit sand from Kent two parts; Portland cement one part.

No. 7. Thames ballast to pass a 1½-inch ring three parts; clean pit sand from Kent two parts; Portland cement one part.

The floors were loaded with 2 cwt. per foot superficial, and the tests were made when the concrete was about six weeks old.

The fire under the floors was kept going for three hours; the temperature was ultimately raised to about 1,900 degrees Fahr. and water was played on and under the floor from two ½-inch hose pipes.

The following was the result:—

No. 1. Slag concrete and pit sand. *Top.*—Cracked across in two places into about three equal parts; deflected about ¼ inch in the width. *Soffit.*—Slight cracks visible corresponding to those on top.

No. 2. Broken brick concrete and pit sand. *Top.*—Cracked across in three places dividing it into four unequal parts. *Soffit.*—Slight cracks visible corresponding with those on top; deflected about ¼ inch.

No. 3. Granite and pit sand. *Top.*—Cracked across in three places dividing it into four parts; deflected ½ inch. *Soffit.*—About an inch of concrete washed off the surface in one part, and somewhat less over the remainder, through the force of water from the hose pipes.

No. 4. Burnt ballast, no sand. *Top.*—No cracks; no deflection. *Soffit.*—No cracks. About 3 inches in thickness washed off the surface in one part from same cause as No. 3.

No. 5. Coke breeze concrete; no sand. *Top.*—No cracks; no deflection. *Soffit.*—No cracks.

No. 6. Furnace clinker and pit sand. *Top.*—Cracked across in two places into about three equal parts; deflected ⅜ inch. *Soffit.*—Pitted in places about 1 inch in depth where struck by water; one slight crack.

No. 7. Thames ballast and pit sand. *Top.*—Bad cracks over almost the entire area; surface damaged more than any of the others; deflected about 2 inches. *Soffit.*—Bad cracks over entire area; surface damaged all over, and a hole in one corner through which daylight was visible.

What we learn from these experiments is that the best materials for concrete floors, for carrying loads when heated and to resist fire, both points considered, stand in the following order:—(1) Burnt ballast and coke breeze equal; (2) broken brick and furnace slag equal; (3) furnace clinker; (4) broken granite; (5) Thames ballast.

This is somewhat at variance with experiments I made many years ago, and which resulted in the following order:—(1) Furnace clinker from boilers; (2) broken bricks; (3) furnace slag; (4) coke breeze; (5) burnt ballast. Broken granite and Thames ballast are so palpably unfit for floors, both by weight and known disintegration from fire, that they were not experimented with. But my trials were

of the rough and ready order, whereas those under the supervision of the British Fire Prevention Committee were made under the best possible conditions.

But unless the concrete is thoroughly dry and the water used in the making has entirely evaporated, the result will be the conversion of the latter into steam, and which must from expansion be an important factor in causing disintegration.

Clearly, therefore, if you want concrete that will stand fire, it must be made from materials that have been produced by and passed through fire. Very few natural stones or gravel will resist fire, and yet we are so conservative that because Thames ballast was at one time—and there is nothing better still—used for concrete in foundations, it was contended that it was the proper thing for fireproof floors, until Captain Shaw, the ex-Chief of the London Fire Brigade, forbade his men from going in a burning building that had floors of this character, knowing from experience that their collapse was almost a certainty. A short time since floors constructed of granite were advertised as the most fireproof of any, and coke breeze is still objected to by many persons by reason of the contention that it will burn almost as rapidly as coal. Experiment 5 proves the reverse.

Why broken brick should stand so bad is not clear; burnt ballast is identical in all respects thereto, and while burnt ballast is often objected to as an aggregate, broken brick is approved.

But practically the resulting difference of the trials is so small that we may reasonably come to the conclusion that furnace slag, broken brick, burnt ballast, furnace clinker, and coke breeze are first-class materials for fireproof floors, and that granite, and most or all other natural stones, Thames ballast, pit, and river gravels, and the like are the reverse.

Another point bearing on these tests is the amount of sand used. As previously stated, the actual amount of the

finest proportion—whatever it may be—should be limited, so that the superficial area of the constituents should be as small as possible, to enable the cement to do its work.

In the series of tests just given we find that two out of the five parts of aggregate were all of one size, *i.e.*, pit sand in five of the trials, and probably—as most pit sands are of a silicious nature—not of a fire-resisting character. Two bushels of sand were mixed with one bushel of cement, and the cementing medium may therefore, for practical purposes, be described as cement mortar two to one, and as a cementing medium two to one cement mortar is about 35 per cent. only of the strength of neat cement.

It is interesting to notice, too, that the two tests made where *no sand was used*—coke breeze and burnt ballast—gave the best results, and although burnt ballast and broken bricks are of the same nature, and should give equal results, the latter had pit sand mixed therewith, and so came out of the ordeal the worst of the lot, granite and Thames ballast excepted.

It will be noted that the width of each of the trial slabs was only about 2 feet 7 inches between supports, and that their edges were free to expand or contract. The experiment was simply to ascertain the best fire-resisting materials, but there are many other things should be determined in conjunction therewith, but which would mean a large expenditure of money. For instance, whether it is desirable to employ steel joists fairly close together and the concrete in narrow sections, as in these tests, or to use as few as possible and depend upon the concrete itself as the fire-resisting material, and with fewer supports. The fact that concrete, after it has become red hot, loses much of its strength, points to more supports; on the other hand, it is the steel beams and joists that usually cause the mischief in a large fire. The plastering of steel beams and concrete floor soffits is an excellent protection for a limited period, but will not stand the effect of water from fire hose, or of a moderate fire for very long.

The effect of embedding steel in various forms to resist tensile strain is another thing that requires to be determined. That it increases the strength of concrete is now well known, and so is the fact that when expansion takes place from great heat the expansion of the reinforcement has no appreciable effect on the concrete. Mr Hyatt proved this by a series of trials many years since, and others have done so since.

The expansion of aggregates differs considerably. According to Hurst common brick expands when the temperature is raised from 32 degrees to 212 degrees Fahr. one part in 1,818, granite one part in 1,267, fire-brick one in 2,365, Portland cement one in 934, mortar of Portland cement and sand one in 848, concrete of Portland cement and gravel or ballast one in 700. Crushed brick and fire-brick aggregates appear to be the best for withstanding a high temperature, so far as expansion is concerned.

From the report of a special committee appointed by the American Society of Civil Engineers with regard to the effect of the fire in San Francisco, we learn that where the plastering was direct on the hollow block floor soffits it was completely destroyed, showing that it is no kind of protection to that class of floors in case of fire. Where hung ceilings below the floors, formed of plastering on metal lathing, were adopted, the plastering was destroyed in a few cases, while in others, where the plastering did not collapse, the floors were saved. Plastering on concrete soffits of floors or on terra-cotta, or cement block floors not provided with dovetail grooves, is never safe from falling at any moment, and absolutely certain to fall in case of a fire.

The report stated that one of the most obvious lessons taught by the fire was the protection afforded to floors and beams by suspended ceilings of steel lath and common plastering. In all cases it was found to give complete protection, and where not used the concrete was destroyed and beams distorted.

CHAPTER XV.

THE CONDUCTIVITY OF CONCRETE.

POSSIBLY the only disadvantage of any real importance that concrete possesses, and a difficulty that would appear not easily surmounted, is its capability of conveying sound; and the harder the aggregate and stronger the cement the better conductor it becomes. It is somewhat singular that Mr Henry Reid, in his treatise on "Concrete," in enumerating its advantages, should have claimed superiority for this material because of its "impermeability to sound," and that Mr Tall, in a paper read before the Architectural Association, should also have declared, after having erected a large number of concrete buildings, that "there was no foundation for such assertion," whereas a concrete wall 9 inches thick conveys sound equal to a brick wall of half that thickness; but lime concrete is not so good a conductor as cement concrete. For ordinary houses, a lime concrete wall 9 inches in thickness would not probably pass sufficient sound to be considered a serious evil, and the plastering on both sides would also assist in deadening it. It has been suggested to batten and lath and plaster concrete partitions to prevent sound passing through, but the evils attending battened walls do not permit recommending this; probably the better way would be to build them hollow, but this incurs much more trouble with concrete than with brick, the only practical way being to insert taper wood cores, 1 or 2 inches in thickness and of convenient size for removal, in the walls during construction, withdrawing them as the work proceeds, or the

insertion of sheets of dry hair boiler felt in the middle of the concrete. To stiffen the felt, it might be tacked to thin rough boards of convenient lengths, both boards and felt being built in. But the disadvantage for dwellings of conveying sound is a matter of no inconsiderable gain in the case of concert rooms, theatres, lecture halls, and other public buildings, for concrete walls create a reverberation superior to any other wall material.

In my own experience I have known conversation in an ordinary tone distinctly heard in an adjoining room where the partition wall was of concrete 6 inches thick, and plastered on both sides. But those who were talking and the listener were near the partition.

Where the passage of sound is a great objection, solid partitions, whether of concrete, concrete blocks, plaster slabs, or brickwork less than 9 inches thick, should be avoided. Nothing but hollow partitions, the hollow being continuous throughout, as far as practicable, can be called sound-proof, and this assertion must be qualified even then.

The conductivity of concrete is found to be a serious evil in the case of solid, or partially solid floors and internal partitions. The only remedy, and an effectual one in the case of concrete floors, is to construct suspended ceilings, as far as practicable independent of the floor. Mr E. T. Hall, who has had a very large experience with concrete, says: "The objection to the solid concrete floor is that it is not impervious to sound; the only way to remedy this is to get an air cushion beneath the floor itself and to suspend the ceiling."

Terra-cotta hollow block floors are claimed to be sound-proof, but except that the cavities help to deaden the sound, they are not so. Walls, whether of brick or stone, have a good deal to do with the transmission of sound, and which is often ascribed to the floors; this is proved by the fact that sound from apartments over is more distinct if the origin of the sound is near a wall, and that a person talking loudly in the middle of a room is heard less

distinctly than if standing near a wall. Another result is that the passage of sound is more in evidence if the room over is of small size. Sound through floors is also diminished in accordance with the height or pitch of rooms, both under and over.

Carpets, as is well known, assist in deadening sound, being of loose texture; the furniture of a room assists in the same direction.

A writer states that from experiments he made he found that the presence of a number of persons in a room lessened transmission through absorption, and this was more apparent when the occupants were women, owing to the nature of their apparel.

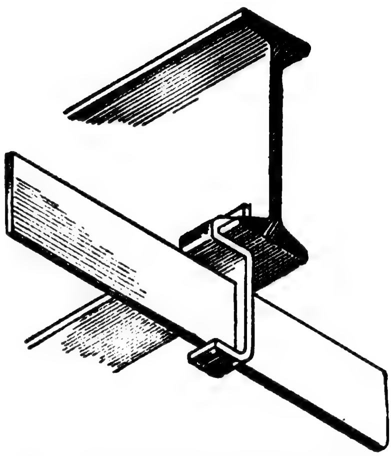


FIG. 110.—Potter's Suspended Ceiling.

One of the great objections to semi-detached suburban dwellings and connected houses is the passage of sound through the party walls and floors. If party walls were built with a 2-inch cavity and a half brick in thickness wall on each side, and suspended ceilings by means of iron lathing bars fixed with hangers to the wood joists and to which steel lathing was attached, houses of this character would be practically sound-proof.

Fig. 110, which I have patented, shows how lathing bars and steel lathing can be attached to concrete floors to form an air cushion, and Fig. 111 a method of adapting the same principle to ordinary wood floors, and which has the additional merit of rendering them to a great extent fire resisting.

The extra cost of the latter over ordinary fir lathing to wood joists is about 1s. 6d. a superficial yard.

None of the ordinary type of hollow slab or block, or solid block partitions can by any stretch of the imagination be called sound-proof.

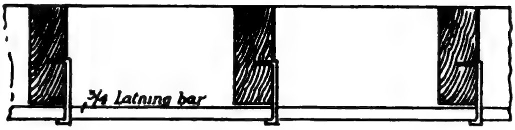


FIG. 111.—Suspended Ceiling.

Concrete in a wet state conveys sound much more readily than when dry. Floors which convey sound when first constructed will often become sound-resisting in course of time.

CHAPTER XVI.

CAST CONCRETE.

CAST concrete is the term usually employed to define such articles in common use as cornices, copings, sills, lintels, &c., and generally called artificial stone. Building blocks and facing slabs come within the category of cast concrete, but have more a field to themselves, although the method of manufacture is practically the same. The great advantage of cast concrete is that frost has no effect upon it, nor does the sulphuric acid in the atmosphere of large towns appear to affect it. In London a considerable quantity has been exposed for at least thirty-five to forty years without injury.

It was formerly the custom, and is now to some extent, to chop soft bricks to the rough section of an intended cornice, coping, or pier cap, and cement them together; then with a plasterer's mould "run" the moulding, *i.e.*, finish the rough core with cement and sand to correct lines, and in this way imitate stonework. Thousands of projecting cement copings and cornices are formed in this way in London and elsewhere, but should the cement crack and allow the rain to penetrate and the frost to obtain a hold of the inferior bricks used as a core, a collapse is imminent, and portions of the overhanging cornice or coping may fall to the ground, to the danger of passers-by. If instead of brick a rough wood mould was made to the outline of the cornice, and the core made of concrete sufficiently wide to rest upon the wall at least double as much as the portion

which oversails the wall, no accident of the kind would be possible.

The *in situ* system of performing this class of work was introduced by Mr Millar, and carried out to a large extent on the Redcliffe estate, West Brompton, about forty years ago, and is probably nearly or quite the earliest attempt of the kind in this country.

There are two distinct processes of casting concrete: one is to use sand as an aggregate, usually one part of cement to three parts of sand, intimately mixing the ingredients, first dry and then sprinkling them with sufficient water only to form a pasty mass of a consistency which when squeezed retains its form without adhering to the hand. When in this state it is placed in the mould in layers of about 2 inches in thickness, each layer being beaten with wood mallets and tampers, *i.e.*, wood rammers from ½ inch to 2 inches square, and from 6 inches to 18 inches in length, according to the size and shape of the mould. Castings made in this way, if the moulds are clean and true to shape, have a surface like freestone; on the other hand, if slovenly performed and too much water is used, the cement settles to the face in patches, and has a blotched and blurred appearance when removed from the moulds.

Mr Millar introduced a similar process for making architectural ornaments and enrichments, the first use of which was on the Redcliffe estate, and which appear to be sound at the present time.

The other system is to plaster the face or bottom side of the mould (and the mould should always be made for the fair or seen side to form the bottom) with the smallest possible amount of neat cement—called slip—with a small trowel; sometimes a plastering trowel, or a small parallel trowel made for the purpose is best; anything indeed that is found handiest and quickest in execution. The mould is then filled in with ordinary concrete, and the smaller the casting so in proportion should be the size of the aggregate.

It will be self-evident that good concrete castings are only possible when the moulds are clean, *i.e.*, smooth and true to the drawing furnished. In an ordinary way this is by no means difficult, but when the casting is composed of undercut mouldings and delicate members, it is not so easily accomplished, and instead of wood or metal jelly moulds have to be employed, which, being of an elastic nature, allow the casting to be withdrawn without clinging, or, as more generally called, "sticking fast," and without breaking more fragile portions. When work of this kind has to be performed it belongs more to the business of the modeller, and scarcely comes within the designation of concrete work.

Wood moulds can be used for concrete castings up to a certain point, but if a considerable number of the latter are made in a wood mould the surface wears rough, and the grain of the wood becomes ridgy, the result being that the cement surface of the casting is not so smooth as it should be, and is liable to stick to the mould and give some trouble in releasing it. Fifty to a hundred castings is probably as a rule the maximum number which one mould of an irregular character will well do for. A curious result sometimes happens when the hard veins in the grain of the wood become prominent, the figure of the latter being plainly stamped on the face of the casting. Pitch pine and red deal appear to be well adapted for moulds, and no great advantage is gained by using harder woods.

In constructing wood moulds the points to be observed are:—(1) There must be no undercut members; if these are indispensable then such portions must be loose and come away with the castings; (2) they must be made so as to readily take asunder and as readily be fixed together again, the smaller and lighter the casting the more necessary this becomes; (3) for large castings the wood must be so arranged that it does not, through expansion from moisture, break the casting in the mould; (4) the wood itself must not be too light or thin, so

that warping or twisting is easily brought about. After two or three castings are made in a mould it will be found that through the pores of the wood becoming filled with cement very little change of form takes place, and also that the castings leave the moulds much more readily.

There are no set methods for making forms; a common-sense joiner will soon develop ideas of his own in this respect, especially if he sees castings turned out a few times and observes where they give any trouble, or cause a waste of time. Fig. 112 is a plan, and Fig. 113 an

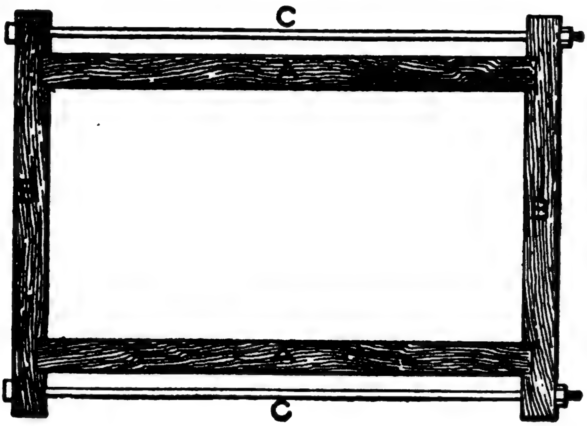


FIG. 112.—Casting Form.

elevation showing the simplest form of mould adapted for lintels, templates, &c. A A are the sides, B B the ends, and C C ½-inch bolts and nuts; no bottom is required.

The sides and ends should not be less than 1½ inch thick, the former grooved into the latter, and held together by the bolts and nuts. The mould should be laid on a wide board or platform, and the inside brushed over with linseed oil, or oil and petroleum mixed—any fatty oil will, however, serve the purpose—then very slightly plastered with neat cement, just sufficient to cover the entire surface area of the visible portion of the casting when fixed in

place. Some little difficulty may occur at first in making the cement adhere to the oiled wood. Before use it is advisable to let all wood moulds soak in a tub of water, otherwise the water contained in the concrete will cause the wood to expand, and as a result where there are small members—as in a cornice moulding—strain and break them. Where the casting is a large one and does not require a smooth face, no bottom is required, as in Fig. 113; in that case it is best to weight the mould to keep it from rising or lifting. The concrete should not be too wet, nor on the other hand too dry; the correct medium in this

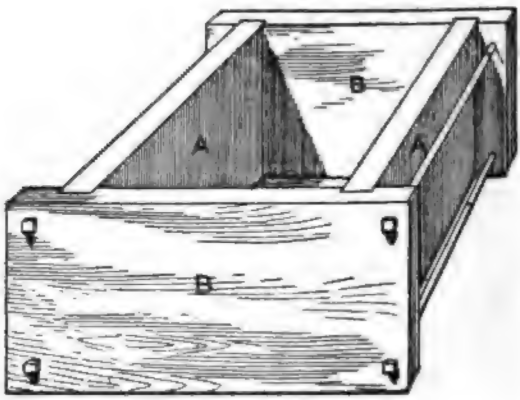


FIG. 113.—Casting Form.

respect will be soon acquired with practice. It is well to make a few holes in each side at intervals, about ¼ inch in diameter, to allow any excess of water to pass away, and the confined air to find an exit. If cement is seen to ooze out with the water to any extent, it is evidence that too much of the latter has been used. In twenty-four hours—or longer if found necessary—the bolts may be released, the sides and ends taken away, and the casting allowed to remain for a time to acquire strength before removal. If the mould is not to be re-used at once, it should be placed in water, or better still—in my own experience—

filled with wet sawdust and kept out of the sun and away from drying winds. These precautions will make a wood mould last much longer than it otherwise would.

It will be found that the first two or three castings from a wood mould may be considerably pitted with air holes, and the cement face disturbed; such defects must be made good with neat cement, *i.e.*, cement without sand. Care should be taken that the cement is not unseasoned or over limed; if unseasoned it will be found to adhere to the wood, and the face probably develop hair cracks as the casting dries after removal from the mould.

If the casting is of a more pretentious character—a

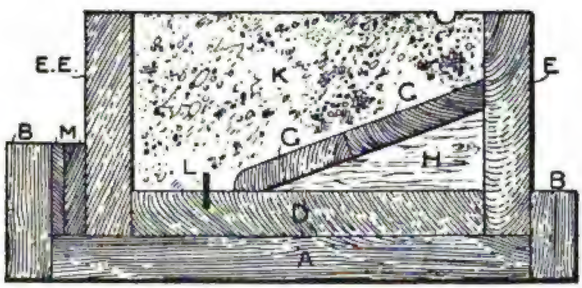


FIG. 114.—Window Sill Form.

window sill for instance, as Fig. 114, a different arrangement is necessary. Two bearers A, with sides B firmly nailed thereto, for the mould to rest on are advisable; A may be made out of 3-inch by 1½-inch stuff; B B of any suitable depth, and 3 inches by 1¼ inch in width and thickness; D is the bottom of the mould; E a fixed side nailed to D; E E a loose side, E and E E being 1½ inch in thickness; H is a block 1½ inch thick and a foot or more apart, fixed to D and E; G G ¾-inch thick linings firmly nailed to H; G G are in two widths as shown, to prevent twisting or warping. A groove for an iron tongue is made in D, and a piece of iron bar ¼ inch thick fixed in same; M folding wedges to bring the side E E tightly against the

bottom D. When about to cast a sill, first lay the bearers on a bench or platform for the mould to project an inch or so beyond them, and wedge it up as shown; the surface of the mould is next oiled and then thinly cemented; concrete is put in gently and tamped or rammed; use a little cement about ½ inch thick to take the place of concrete along the underside and outer edge of sill, and a water groove can be formed in the cement with a piece of sheet iron cut to the shape and fixed to a gauge stick. In the course of two or three days turn the mould upside down on the platform, block the ends up an inch or so, release the wedges M, and if the sill does not at once leave the mould, tap the latter gently with a stick or hammer, and the

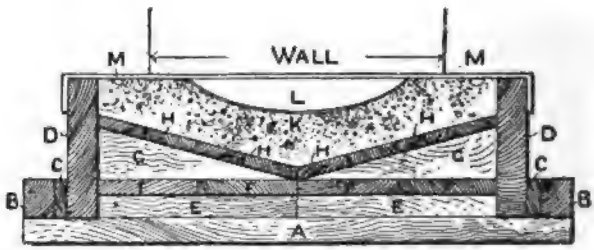


FIG. 115.—Wall Coping Form.

jarring will soon cause it to drop. A layer of sawdust or sand for the casting to fall upon is advisable. The iron tongue will be found firmly embedded in the concrete. The ends of the moulds may be fixed to the sides with screws, or by means of simple clamps from end to end, or in any way found most convenient. If the mould is deep, wood clamps may be fixed across the sides to keep them from spreading.

Fig. 115 is a section of a wood mould adapted for casting a limited number of wall copings. A is a bearer made of 3-inch by 2-inch stuff, having two side pieces B B nailed firmly thereto; D D are the sides, of suitable dimensions; E E are ledges about 4 inches by 1½ inch upon

which the bottom boarding F F is nailed; G G are blocks $1\frac{1}{2}$ inch thick and about 9 inches apart, fixed to F; H H are $\frac{3}{4}$-inch boards in narrow widths, forming the bottom of the mould and the face of the casting fixed to G.

Two bearers are required, upon which the mould is laid and kept in place by the wedges C, and light iron or wood clamps are put over the top to keep the sides from spreading; water grooves M are made in the same way as described for the window sill, Fig. 114. Ends may be screwed on to the sides temporarily, and hollowed out to form a guide for shaping the concrete, to save materials and weight. This mould is shown in two halves, because for a wide coping it would be more advantageous and convenient to handle; if in a single piece the boards might burst from expansion. The diagrams as shown are quite sufficient to explain what is required in making concrete moulds of wood; a competent joiner will soon of his own knowledge determine the simplest way of constructing them for almost any purpose.

If many castings are required it is quite possible to cover the various parts of a mould of this kind with sheet zinc tacked to the wood, but using tacks or flat headed nails with discrimination, that the casting may not show the impression of more nail heads than is actually necessary to keep the zinc in its place.

Cast-iron moulds are usually employed when there are many sharp edges or delicate portions in the concrete casting, or where a large number of the latter are to be made from one mould. These may be formed in any way that is the least costly, and which admits of their being readily taken apart to liberate the casting, but it is quite necessary to plane, file, or otherwise make the surface of the iron mould smooth, otherwise the rough surface causes cement to adhere thereto, and it becomes a matter of some difficulty to free the concrete casting.

Fig. 116 is a section of a mould which was used for many hundreds of garden wall copings. The sides and

ends were made of 10-inch by 1½-inch deal, mortised and tenoned together, forming a curb or rim, without a bottom. The extreme length was ·2 inches less than that of the coping, and the ends were cut to the correct shape for the iron castings B to rest upon. The castings were ½ inch thick, made to butt together in the centre, and with a rim all round their extremities, to allow iron ends about ¼ inch thick, and the exact shape of the section of concrete coping E, to drop in and remain fixed; D D are wedges passing through mortises in each end to keep the iron mould firm,

FIG. 116.—Coping Form.

and dotted lines F F the mortise and tenons of ends and sides. When the coping was in a proper condition to be removed, the mould was turned over, the wedges D knocked out, the wood frame lifted off, and the iron sides removed which released the ends. The castings were allowed to stop for some days to attain strength before being handled.

The immersion of concrete castings in baths wherein silicates have been introduced, and Mr Faija's process for the application of moist heat with the object of hardening them more quickly, have been described in connection with the manufacture of paving slabs on p. 160.

CHAPTER XVII.

CONCRETE STAIRS.

WHEN concrete stairs first came into use is as uncertain as when concrete foundations and walls were first adopted. We are apt to look upon concrete stairs as an undoubted modern invention, but they are to be seen in Colchester Castle, and in the keep of Rochester Castle built in William the Conqueror's reign. Millar, in his book on plastering, says that Mr W. B. Wilkinson, of Newcastle, was the first to introduce them in modern times, and that they were first used in London by Mr Allen in 1862, who used shingle and coke breeze as aggregates.

Concrete stairs are superior to those of other materials by reason of being fire resisting and of greater durability. The old theory that stone was the best material came to an end when lives were lost at the old Polytechnic in Regent Street, London, many years ago, through the collapse of the stone stairs during a severe fire.

There is no great difficulty in constructing concrete stairs, more especially when the steppings are cast singly in wood or metal moulds, and made of the same shape and fixed in the same way as stone stair steps. A joiner can construct the mould or form with but little difficulty or previous knowledge, but if the stairs are to be of a monolithic character—usually the practice at the present time—the forms are of an altogether different description. The first thing to do is to provide a template of thin wood, as A, Fig. 117, to show, when applied to the wall, the face line of treads and risers, and C the soffit line when completed.

If the walls are not already built, the bricklayer uses the template from time to time as the work progresses to ascertain where he is to insert soft bricks bedded in sand, called a sand course, that they may be easily withdrawn when the walls are finished, and the stairs are about to be commenced. If the walls are already built, chases or indents have to be cut therein, but the former is the most desirable method where practicable. Sand course bricks should be stretchers, not necessarily whole bricks—bats or half bricks here and there do as well, and no object is gained in the indents being over 4 inches deep; more than this only weakens the walls. It is unnecessary for the sand course bricks to be continuous, nor to cut them to the

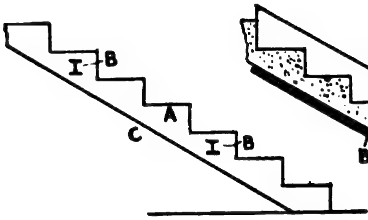


FIG. 117.

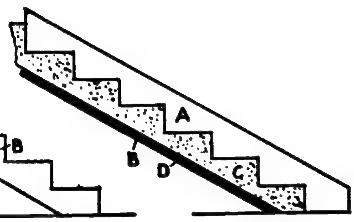


FIG. 118.

rake of the soffit. All required is that they should, when removed, provide ample indents for an efficient grip on the steps. This is more important when the stairs have only one wall to support them, in which case each step is of the nature of a cantilever. The sand course bricks should not project beyond the face of the treads and risers, or below the soffit line, otherwise "making good" will have to be done when the stairs are completed. If the stairs have only one wall to support them, the other side being open, the strength is increased by inserting a piece of iron bar, usually a 3 by 1½ inch joist, in the concrete nearly the full length of the step, wall indent included, to each third step, as B, Fig. 117. Some authorities now require that a light steel joist shall be fixed under the unsupported side of the

stairs as a precaution against a stampede in case of fire or panic, as shown by Fig. 119, and encased in concrete or plaster on steel lathing, a necessary precaution.

The first thing the joiner does when commencing the false work is to temporarily fix to each wall a wood template cut to delineate the actual finish or face line of treads and risers, as shown by A, Fig. 118.

If the stairs are open on one side a supporting form has to be fixed to carry the concrete until it is strong enough to support itself, the template A, Fig. 117, being attached thereto. The form for the under side or soffit of the stairs is usually of inch floor boards, as B, Fig. 118, rigidly fixed

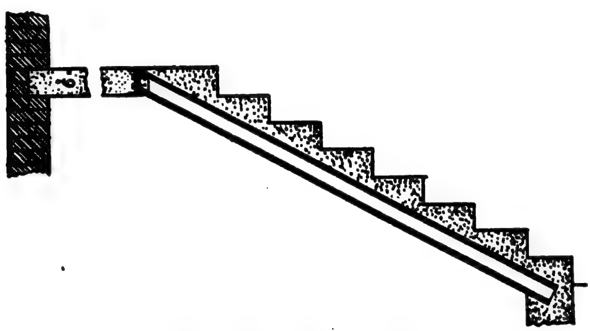


FIG. 119.—String Support.

with props and bearers, and of sufficient strength to allow the concrete C to be deposited thereon without deflection.

The strings and soffit forms being in place, the riser forms, made of 1 or 1¼ inch in thickness boards, are fixed at the ends only as may be found most convenient, as Fig. 120. The bevelled edge of the risers A A is for the purpose of allowing the plasterer means for finishing the treads close up to the concrete riser. The forms for curtail and bull-nose steps, and the circular portions of continued stair strings, and similar details, can be usually better done with plaster of Paris.

Landings are supported by chases left in the walls, or

cut out as may be best, a light joist being fixed behind the last riser, from wall to wall and to which the joist supports for open stairs are sometimes fixed, as Fig. 119. When nosing edges to treads and landings are necessary, an invert mould has to be attached to the riser by nailing, and which is usually the section shown by Fig. 121. In open stairs this has to be mitred and returned to form the end nosings of the treads. The concrete should be filled in to within an inch of the surface of the treads, and the remainder, consisting usually of granitic cement—one of cement

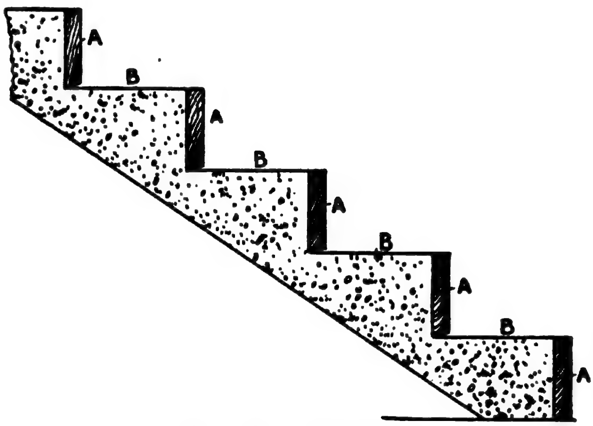


FIG. 120.—Riser Form.

to two of washed granite chips, none larger than would pass a ¼-inch cross mesh—applied and accurately finished by the plasterer with a steel trowel before the main body of the concrete has got too hard. A running-rule can be used for the purpose, made to run against the edge of the nosing form on the front of the tread and to the edge of the nosing form on the next riser above. The nosing forms and face of risers should be filled entirely with fine granitic cement, and previous thereto washed with thick neat cement, using a small painter's tool. If this is done very little making good is necessary when the forms are removed, but what

there is should be done at once and not left for the granitic to get quite dry and hard. Obviously the forms should be washed with soft soap lather, paraffin and oil, or some similar compound, to prevent the cement from sticking, and it should also be left a short time to allow it to penetrate the wood before the concrete is filled in.

Suitable aggregates for stairs are the same as those suitable for floors, but as nails may have to be driven into the concrete, coke breeze, boiler ashes or soft brick débris are the most suitable, either of which should be well

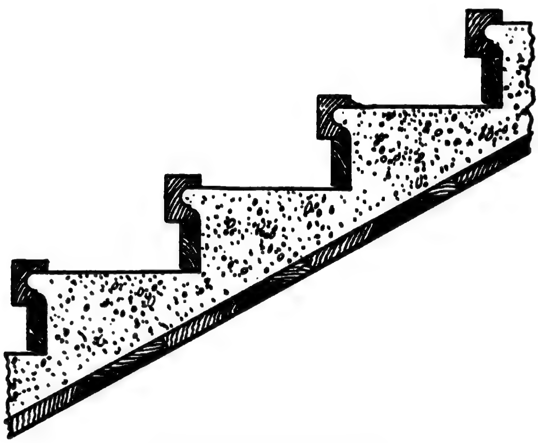


FIG. 121.—Nosing Mould.

saturated with water for some time previous to use, and the concrete, about one to five, not mixed too wet, or the effluent water will rise to the surface; more especially is this necessary for the granitic finish. A very little granite sand may be sprinkled over the surface as a last operation, and well trowelled in.

The risers must be trowelled smooth after the forms are liberated, and previous to the concrete being deposited in place a skimming of granitic should be put on the form to provide a smooth, hard riser surface.

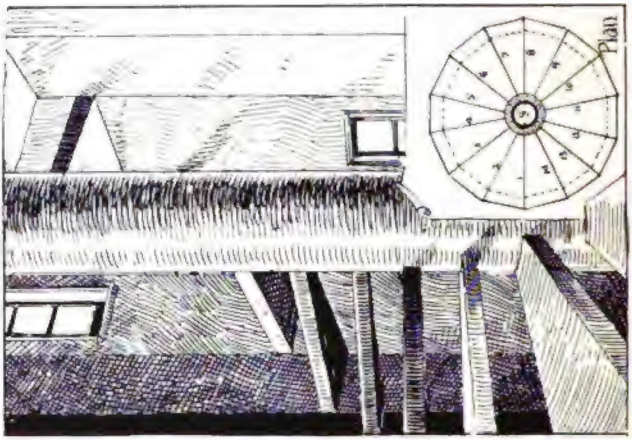


FIG. 123.—Winding Stairs.

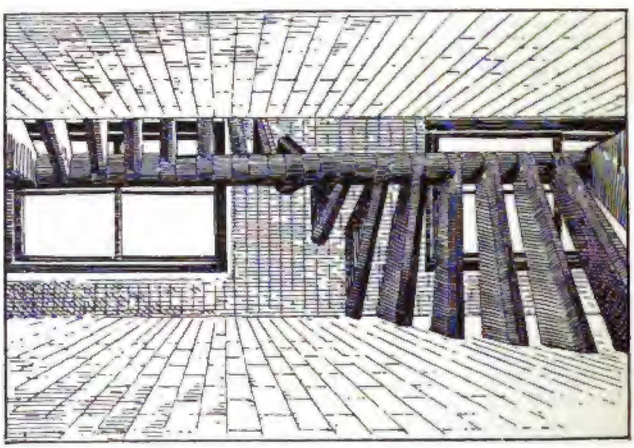


FIG. 122.—Winding Stairs.

Fig. 122 shows an arrangement for cast concrete steps and no risers, the newell being either cast on the steps or in short pieces—the former makes much the neatest appearance. Stairs of this kind are useful for many places where the usual class of stairs is unnecessary. Economy in cleaning is obtained, and light from windows is diffused. Wood moulds lined with zinc are preferable to wood only for this special purpose.

Fig. 123 shows how the newell may be arranged to form a smoke flue. The one illustrated was for the flue of a

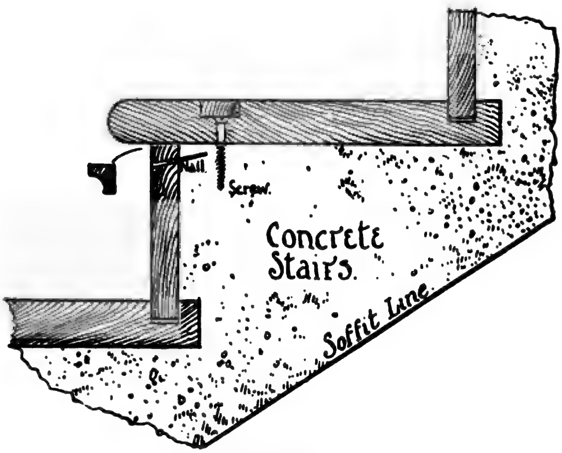


FIG. 124.

heating furnace in the basement, which was carried up a tower stairs to the roof. The flue itself was 9 inches in diameter, and encased with concrete, into which the steps were fixed. The concrete was cemented to a smooth surface. The flue pipe was of the usual kind—unsocketed fire-clay.

Cement surfaces for stairs and landings are sometimes objected to; they are cold and have a cold appearance. To remedy this, wood casings can be readily fixed to the treads, as shown by Fig. 124. When the stairs come

between two walls, and the treads are let therein about ½ inch at each end, a single screw midway between the walls is sufficient, and which will hold equally as well to the concrete as to wood. Wood plugs to screw to should be avoided—they are apt to shrink and get loose and decay. A piece of wood should be let into the tread and glued in over the head of the screw. If wood risers as well as treads are required, and both to be of hard wood, it is necessary to avoid visible nail holes. In this case they may be fixed as Fig. 124, the riser being let into a groove in the tread and nailed or screwed into the concrete near the top, the hollow shown loose being fixed afterward with glue or needle points to hide the nail holes. The wood string linings can be fixed without nail holes being visible, in the same way at top, and at the bottom by a loose return bead fixed with glue or needle points, or both, as Fig. 125.

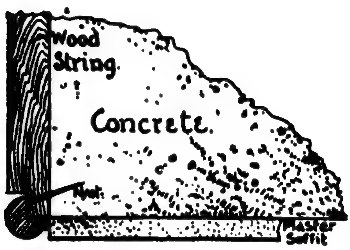


FIG. 125.

An ingenious joiner should be able to devise other ways of casing concrete stairs and other structural work without showing nail holes. But as with floors, it is strictly essential that the concrete should have had time to dry thoroughly throughout, not merely on the surface, before being cased with wood, or failure will be the result.

CHAPTER XVIII.

Concrete for Landed Estates.

For buildings and many other purposes on landed estates concrete is, or should be, an important factor in construction. It cannot be said, however, that as yet it has, for estate purposes made much headway, and for this there are reasons.

Most landed estates possess brickfields or lime kilns or stone quarries, and for which no rent is paid, or if there is it is by tenants on the estate, who make their living therefrom. Owners, too—very properly—like the character and design of their new buildings and the materials of construction varied, and cost is not always the first consideration.

For farm buildings exposed to rough usage, however, concrete is the best material, all points considered, but for cottages and farmhouses the same claim cannot always be maintained.

Aggregates of a suitable nature can be found on most estates; if otherwise, crushed brick débris, furnace ashes from the nearest town, or railway locomotive ashes from the nearest station are usually obtainable at a low cost.

Monolithic walls for farm buildings seldom require to be more than 9 inches in thickness, as the latter are never over two stories in height — the ground floor and the floor above. In my own experience I have never made them over 12 inches thick, and there is nothing gained in making them more. The best form of coping for farmyard, boundary, and enclosure walls is of a semicircular section,

formed *in situ* by fixing half circle wood templates, as shown, at about 10 feet apart, and using fairly fine concrete one to six or one to seven; Fig. 126 is the wall, and Fig. 127 a wood template. Two workmen with a straight-edge 10 feet in length can readily form a neat coping in this way at a small cost. No throat or drip groove is practicable with a coping of this kind, nor is any necessary, for, unlike brick or stone walls there are no mortar joints to be washed out, or absorbent bricks or stones to become indurated with rain and shattered by frost. Moreover, rain on concrete boundary walls does no injury, and where projecting copings of other materials are used, they are always subject to damage from live stock.

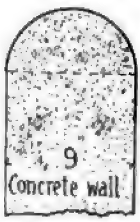


FIG 126. FIG. 127.

Concrete paving can be applied to every description of farm buildings, and is superior to any other material for the purpose. For stables V-jointed granitic paving $1\frac{1}{2}$ or 2 inches in thickness is equal in durability to blue bricks, and is jointless. It has been used for cavalry stables for many years. It should be laid on a few inches in thickness of dry core, as described on p. 216.

Locomotive ashes, or boiler ashes of almost any kind, one to five, and about 4 to 5 inches in thickness, on a hard, dry bottom of rough stones or brickfield débris, is the most suitable for cow houses, bullock sheds, and piggeries. It should be well beaten and laid straight, and true to screeds fixed at intervals of 7 to 10 feet, and in alternate squares, chess-board fashion, the screeds being removed as the

vacant squares are filled in. After two days' interval it should be grouted with grout made of half cement and half sharp sand, or washed ashes sand, passed through an eighth mesh sieve, and of the consistency of cream, and well worked in with a broom.

Floors of this kind can be done cheaply, and are extremely durable and sanitary. V-jointed flooring for piggery, cow-house, and calf-house floors is unsuitable; the joints become clogged with manure, and are uncleanly, nor is it necessary, as cinder or ashes floors are non-slippery, nor do they wear slippery, and can be used within a week after completion.

Piggery walls, usually about 4 feet in height, with divisions every 8 or 10 feet or less, need be no more than 6 inches in thickness; there is no advantage in being thicker. Floors of implement sheds, meal stores and similar places may be of the same description as for cows and pigs as just described: it pays to pave almost the entire ground area of the buildings of a farmstead in this way if only for one reason—protection against rats, the pest of a farmstead. Rats will make a way through a brick wall, and upheave brick and stone paving with an energy worthy a better cause, but to concrete they have a decided objection. I have known rat-infested farmsteads to be practically deserted when the old wood, stone, and brick pavings have been taken up and concrete substituted. Like a good general who provides a safe retreat for his army, rats are careful in their movements. If they find their line of retreat—their holes—unavailable, they are credited with migrating in a body to more congenial quarters elsewhere.

Cattle mangers, Figs. 128 and 129, are superior to wood, and less costly than if formed with purpose-made bricks. The concrete foundation having been put in, a wood frame E, made out of ¾-inch boards ledged together, is temporarily but rigidly fixed to the line of front, and the concrete bottom deposited in place, the curved portion being shaped

with a trowel, and the wood form or mould for the inside fixed and stayed in any convenient way, and the concrete then filled in. The top rounded edges must be done with a trowel. Manger forms 8 to 10 feet long is a convenient size, and when one length of the manger is completed, the form can be moved and refixed for another length. The concrete should not be larger than would pass a 1-inch mesh screen. As there is but little pressure on the form it need not be thicker than ¾ inch.

Fixings for the ties, or ropes, or chains to secure the animals are usually necessary, and I know of no better

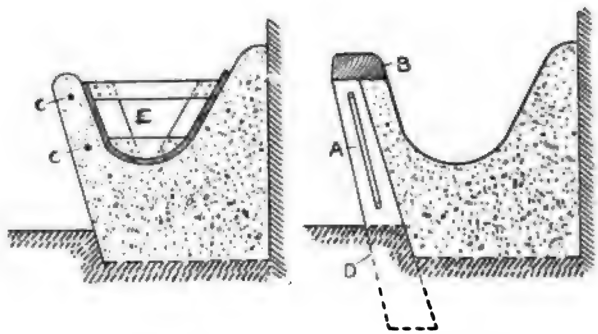


FIG. 128. FIG. 129.
Cattle Mangers.

plan than posts D, about 4 by 3 inches, with their outside edges rounded, fixed in the ground with a cap rail attached thereto, and a sliding iron A driven into the side to admit an iron ring to freely work up and down, as Fig. 129. C C are reinforcing rods.

Pig troughs can be formed in a similar way to bullock mangers, or cast in one piece to be movable.

Food shoots on the outside walls of piggeries, Fig. 130, can be cast in one piece of concrete; these have found more favour with agriculturists than wood or stoneware. A A are reinforcing rods; C the end of shoot on which the bucket rests at D.

As most persons connected with landed estates are aware, the maintenance of fences is an important item in the expenditure. Iron fencing is of course preferable to wood where the ground is solid, but there are occasions where it cannot be used to advantage, soft ground for instance where it is difficult to make it rigid enough for cattle enclosures.

Larch and Scotch fir are not sufficiently durable for posts; oak is not always available, and when it is, is usually the unsold portion from the annual timber sale, of inferior

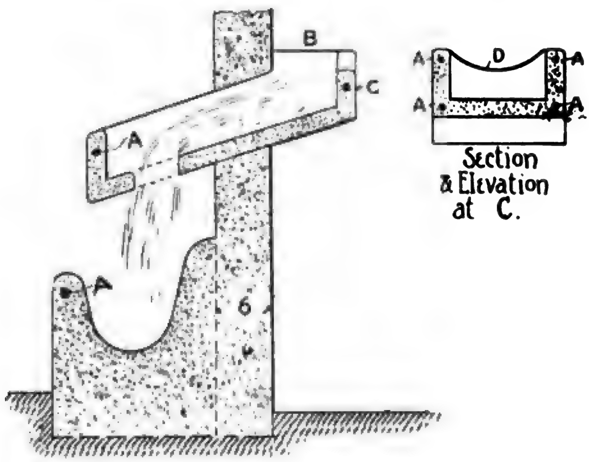


FIG. 130.—Pig Shoot.

quality, principally sap, and has a short life as fence posts. Concrete makes excellent fencing and gate posts. The most convenient size for fence posts is 6 by 4 inches at bottom, and 4½ by 4 inches at top.

A form for making fence posts where iron wire or rods are intended is shown by Fig. 131, and which consists of one side and one end B, 6 by 3 inches, and the opposite side and end B, 4 by 3 inches. These are grooved for 1½-inch thick division pieces, *d, d, d.* A clamp E is required at each end to keep the whole firmly together. F F are

fillets nailed to A A. If circular or splayed tops to the posts are wanted, a loose wood core piece made to the necessary shape can be put in at the top end of the form. If rods are to go through the posts, circular holes somewhat larger than the intended rods or wires must be made through the wood divisions and sides, and temporary rods G inserted before the form is filled with concrete. Ample space should be allowed for the permanent rods or wires to pass easily through after the temporary ones are withdrawn. The latter should be bent at the ends to afford means for pulling

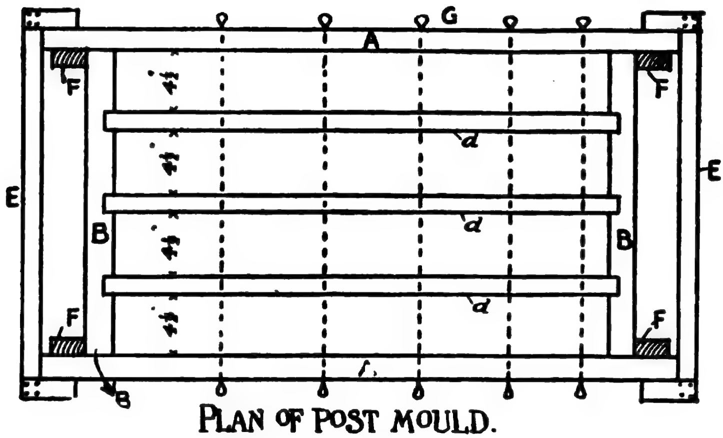
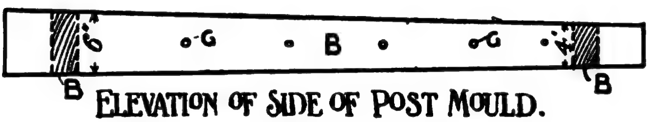


FIG. 131.

them out, and which should be done within two or three hours after the concrete has been deposited in place, or they will be difficult to move. B, Fig. 132, is an elevation of the form side, and C elevation of the wide end. The form should be laid on a wood or other floor, and all the parts brushed over with oil, grease, or soap lather to prevent the concrete adhering to the wood. Forms should be made of foreign fir, or any English wood not liable to twist or warp. Except the divisions, the form can be liberated in twenty-four hours, and the divisions when it

is found that the posts can be handled without breaking, so that double or treble the number of divisions are wanted for one set of sides and ends. As soon as removed, the posts should be washed over with liquid cement of the consistency of cream. Two coats are preferable to one. Posts 6 feet long, 6 by 4 inches at one end, and 4½ by 4 inches at the other, will weigh 60 to 70 lbs., according to the nature of the aggregate, and cost 1s. 3d. to 2s. each, and which depends upon local wages rate, and the value of the aggregate and cement. If any old fence rods, wires, &c., are available, and of no other use, one or more inserted the full length of the post very much increases the strength.



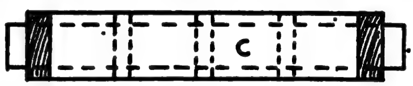


FIG. 132.

Where live stock are frequently passing through gateways, and occasionally for other reasons, it is often an advantage for a gate to open both ways, and although this can be arranged by hanging the gate in the centre of the post, it is often damaged by being forced against the post in an endeavour to open it wider than the hangings permit. Fig. 133 shows a circular concrete post with a ¾-inch iron rod passing down the centre, the upper part of which forms a hook for the eye of the top hinge. The bottom hinge revolves round a circular iron ring A of 2 by ¼ inch iron built in the concrete. In this way the gate will revolve in any direction. The form is of wood in two halves, and would of course be available for any number of posts. A

gate and post of this description have been in use for twenty-five years.

Underground water tanks for storing rain water from roofs are economically constructed of concrete. For farm buildings a tank 6 feet in diameter, circular on plan and any convenient depth from 10 to 18 feet, but not exceeding

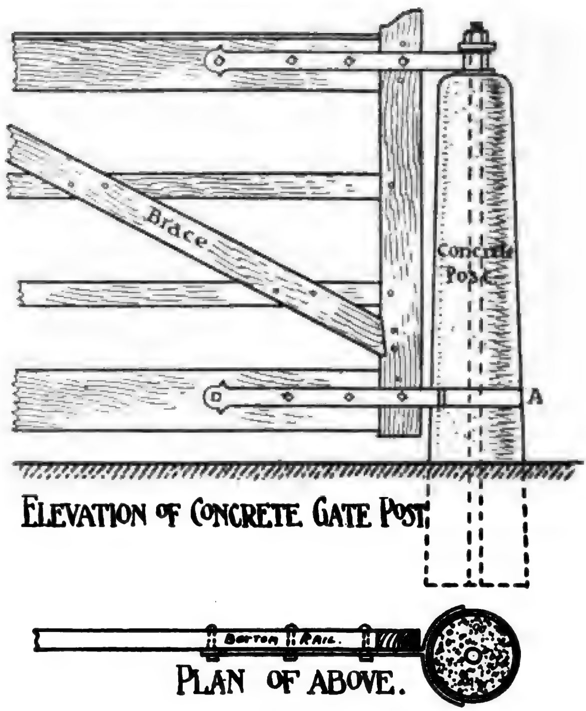


FIG. 133.

the latter or it will be too deep for an ordinary pump, is adapted for receiving the water from roofs of considerable area. A wood drum, of the same description as used for steining wells, is necessary, and made in three sections to allow of being easily withdrawn. But it is cumbersome and costly. A simpler arrangement is shown by Fig. 134,

which is a plan of a 6-feet tank. A is the concrete 9 inches thick. The false work consists of rings of tee iron C C, 1½ by 1½ inch, in three sections bolted together at the joints. Wood props D the full height of the tank are fixed

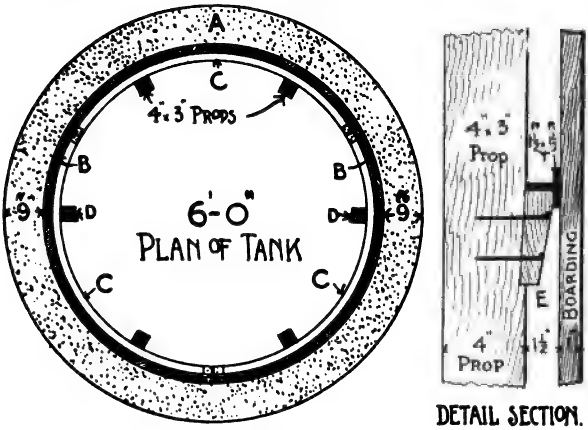


FIG. 134.—Water Tank.

temporarily to support by means of wood blocks the rings C C, which may be 3 to 4 feet apart, and boards B are placed behind to keep the concrete in place. Necessarily the boards have to be the same length as the tank is in depth.

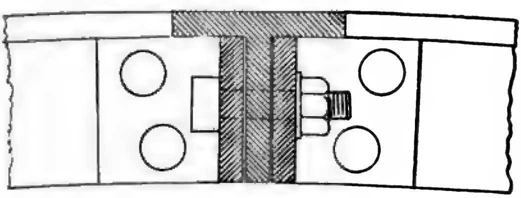


FIG. 135.

Fig. 135 is a larger size detail of section of ring.

A circular tank is much more capable of resisting the pressure of the soil than a square or rectangular one, but where it is wanted to store water for domestic use, and it has to be divided into two portions so that one can be in

use to enable the other to be emptied and cleaned out at intervals, a rectangular one is preferable. For farm use, however, this is unnecessary as a general rule, a common pump being sufficient for the purpose, and when the water in the tank is low the opportunity should be taken to clean it out. For firm soils like chalk, 9 inches in thickness for sides and bottom is ample, but where it is loose or friable or likely to expand, the thickness should be increased. The top can be covered with concrete, six to one, 6 inches thick, resting on boards that bear about 2 inches on the concrete wall. In my experience it was less costly and less trouble to use the commonest 1½-inch boards procurable and let them remain. If percolation from the surface is possible, sand or gravel may be heaped on the boards to form a flat dome, and smoothed over with mortar upon which the concrete is deposited. A manhole 18 inches square should be left in the top to be covered with a flat stone, or by preference a cast-iron manhole cover. The top should be grouted twice with liquid cement, which will keep water from percolating from the outside almost equal to a coat of cement. A 3-inch cast-iron pipe, 6 feet in length, fixed vertically with a wire cover on top is necessary for ventilation. The inside of walls and the bottom should be coated with cement and sand an inch thick, one to three, the sand being very sharp and clean. For cottages a tank 3 feet in diameter and 6 or 8 feet deep is ample for rain water, and where the ordinary supply is hard, or the domestic water is obtained from deep draw-wells, a rain-water tank is a blessing to the occupants.

Suspended floors and roofs of farm buildings of concrete are seldom adopted; the latter cost more than common tile and slate roofs, and the roof area of farm buildings is often of considerable extent.

Water troughs for cattle, mixing troughs for piggeries, door sills, window sills, sluices, and foot and cattle bridges where irrigation to grass lands is practised, can all be executed with advantage with concrete.

CHAPTER XIX.

CONCRETE ARCHES, VAULTING, DOMES, &C.

SUPPORTING arches, domes, vaulting, and similar work can be executed in concrete with many advantages. No templates, moulds, &c., necessary if of stone or brick, are required, and except the forms or centering no preparatory work is required. Sir Gilbert Scott used to say that a concrete arch was like an inverted basin, for there was practically no thrust. This, however, must be conditional, depending largely upon the span, the section, the suitable distribution of the concrete, the load to be carried, if reinforced or otherwise, and surrounding circumstances generally. These are all factors in the calculation, and no general formula therefore can be laid down as to the various stresses.

Obviously the thrust of a concrete vault or arch is very much less than a stone or brick, with their multitudinous cement joints, even without reinforcement. In many cases it is fair to assume there is no thrust whatever, more especially when reinforced. The latter can be of a similar character to other forms of concrete construction, but with the object of binding the mass together in a way that shall leave no one part weaker than another, and which again depends upon the nature of the proposed work.

The stresses upon arched form concrete is naturally influenced very largely by the condition of the concrete when the forms or centres are struck or released, as with flat floors and roofs, and for this reason they should remain in position as long as circumstances permit. The maximum

strength of the concrete is not obtained for a long time after it has been deposited in place, and until then it has a very much less power for resisting the various stresses it is subject to.

There is no doubt whatever that centering for concrete vaults and arches is often struck much too early. The old practice of slacking or easing the wedges or slack blocks of wood centering supporting brick and stone arched work, soon after the work is completed, with the view of adjusting the strains, should not be practised with concrete, which is of quite a different nature. The forms or wood centering should be constructed as for stone or brick, but as the weight of the concrete is usually less, the timber construction does not require to be of equal strength.

The facing of concrete arches with tiles and other thin materials by arranging them in position face downwards on the centering boards and pouring the concrete on to form the arch, has not always been successful. It is difficult to keep the tiles from slight disturbance, and preventing the liquid cement from oozing through the joints and adhering to the face surface and staining the materials. Surface finishing of a plastic character appears to be the best method generally.

The proportion of cement to the aggregate depends upon the nature of the work. Obviously the greater the span without intermediate supports the better quality the concrete should be, not necessarily increasing the thickness, except at the haunches. Whatever thickness is decided upon for the crown of arches or vaults it should be gradually thickened thence to their springing. Owing to the monolithic character of reinforced concrete there appears to be scarcely any limit to the span or distance between supports for which it is available. Figs. 136 and 137 show portions of concrete ceilings at Minterne, Dorchester. The thickness of concrete at the crown was 5 inches and at the haunches 9 inches, and the reinforcement consisted of $\frac{1}{4}$-inch diameter steel corrugated rods

FIG. 136.—CONCRETE CEILING, MINTERNE, DORCHESTER.

Fig. 137.—Concrete Ceiling, Minterne, Dorchester.

FIG. 138.—CONCRETE CEILING, ST CHARLES' COLLEGE, NOTTING HILL.

Fig. 138 is a section of the ceiling of the Chapel at St Charles' College, Notting Hill. The clear span is over 30 feet; there are ribs of concrete 4 inches deep at intervals as shown. The centering was struck within a month after the completion of the concrete—much too early. The thickness of concrete at the crown is 6 inches. The ceiling supports a timber and slated roof. The photograph was taken immediately the centering was struck.

These specimens of vaulting were executed by Potter & Co. Limited.

CHAPTER XX.

Staining Cement.

The practice of colouring or staining cements, fit for external work, when in a soft state and previous to their application, does not appear to have arrived at a decided stage of success. The nature of Portland cement renders it difficult to be dealt with in this respect, for it does not maintain uniformity of colour, eventually becoming "spotty." Experiments proved that bullocks' blood mixed with cement in the proper proportion, produced a tone of colour exactly resembling the best red rubbers, and in the hands of a competent man who trowelled the surface with very fine grit, rustic quoins, arches, &c., were formed which might deceive most people, but there are objections to the use of this colouring material, and in a general way it is not a desirable practice.

There are many substances that are adapted for this object, but some, such as Venetian red, Spanish brown, ochres, and other materials of an earthy nature, very considerably impair the quality of the cement, and should be used with caution. Mineral oxides form a very efficient stain and with but little injury to the cement; one part of red oxide to six parts of cement gives a purple-red colour to the casting; manganese mixed with other materials will produce various shades; but whatever may be employed for the purpose it is best to first try various proportions with small quantities of cement, and select those which may be considered most desirable. It is a mistake to suppose that finely ground red brick dust forms

a good dye for red concrete; it simply turns it of a pale unbaked brick tint. The staining matter is the impalpable dust that adheres to the broken bricks through the percussion arising from crushing or hand breaking.

Mr Hodson, an engineer, tried many experiments for the purpose of finding the best materials and most suitable proportions for colouring cement, and sought a patent for that object, but which was not granted. Mr Hodson used oxide of iron free from clay or deleterious matter, from the Malago Vale, near Bristol. For a buff stone colour he employed eight parts by weight of yellow oxide of iron, one part of red oxide, and thirty-six parts of cement; for Caen stone colour, four parts of yellow oxide, one half part of red oxide, and thirty-six parts of cement; and for dark red colour, nine parts of red oxide with thirty-six parts of cement.

A writer in *Concrete and Constructional Engineering* gives the following list of materials and their proportions to obtain different tints:—

RED.

87 parts fine ground Portland cement.
11 „ oxide of iron.
2 „ black oxide of iron or copper.

100

YELLOW.

84 parts fine ground Portland cement.
14 „ yellow oxide of iron.
2 „ black oxide of iron or copper.

100

BLUE.

80 parts fine ground Portland cement.
18 „ azure blue or ultramarine.
2 „ black oxide of iron or copper.

100

GREEN.

85 parts fine ground Portland cement.
12 „ oxide of chromium.
3 „ black oxide of iron or copper.

100

CHOCOLATE.

88 parts fine ground Portland cement.
6 „ black oxide of manganese.
4 „ red oxide of iron.
2 „ black oxide of iron or copper.

100

BLACK.

87 parts fine ground Portland cement.
13 „ black oxide of manganese or any carbon black.

100

WHITE.

67 parts fine ground Portland cement.
33 „ powdered chalk or sulphate of barytes.

100

In deciding the tint required for staining cement, specimens containing different proportions of the colouring matter and cement should be made and allowed to become quite dry before coming to any decision thereon, as they invariably dry paler. Apparently the colours in the course of years fade to some extent, probably owing to the chemical action of the lime contained in the cement. For this reason staining cement is not a success when used on large surfaces, as, for instance, in stuccoing brick or concrete walls. In mixing the ingredients the greatest care is necessary, and exactitude in the proportions employed. If improperly or inefficiently mixed, the surfaces of the slabs or castings are apt to go spotty and patchy. On the whole, the staining of cement is not as yet an entire success.

Mr S. H. Cohn, of King William Chambers, 27 and 28

King William Street, London, who has been a manufacturer of colouring materials for many years, says they are proof against alkalies, and are manufactured from iron oxide, iron oxide hydrate, chrome oxide, zinc oxide, zinc sulphide, manganese oxide, &c., and that the quantity required is so small that the strength of cement is very little diminished.

CHAPTER XXI.

THE SHRINKAGE OF CONCRETE.

IT is to be feared that many contracts have been taken for concrete under the assumption that a cubic yard of an aggregate will make—with the assistance of the cement—a cubic yard of concrete. When the work was complete it was probably found that much more aggregate had been used than the concrete measured.

Presumably, there are very few persons to be found at the present time, however, who would make such glaring errors of calculation as Mr Tall (p. 86), who in estimating the cost of concrete calculated upon 16 bushels of cement to 1 cubic yard instead of 21, and 14 yards of an aggregate making 15 yards of concrete.

It must not be inferred that the aggregate of which concrete is made shrinks or contracts during the process of being converted into concrete—that is not a rational conclusion—but the particles being more evenly distributed and interlocked with each other through the action of the water employed in mixing, and by compression, form a mass of less bulk when made into concrete than that previously occupied by the aggregate alone.

So long ago as 1857, Professor Hayter Lewis, in a paper read before the Royal Institute of British Architects, maintained that there was no diminution in bulk of materials when used for making concrete, and subsequently endorsed his views by publishing the following statement in the *Builder*:—

"The general idea with respect to the material is—1st,

that there is a sensible loss in bulk of the ballast, independently of that of the lime; and 2nd, that the materials on being mixed together, expand considerably. So much is this the idea, that a respectable builder—one, I am sure, quite above stating what he did not believe to be true—required on calculating the price of the concrete, that I should allow him one-seventh more ballast than the concrete cubed to, he depending on the published statements of the loss of the ballast being thus great. It was this demand that first led me to experiment. The same trials were all made in the same manner, and with one exception, I was present at the whole process from beginning to end. Several of the Committee of the Architectural Publication Society also attended at the trials. A wooden box was made, holding exactly 1 cubic yard; this was filled with a fair sample of ordinary Thames ballast, such as is used for concrete in London; to this was added ground Medway grey stone lime, in the proportion of one of lime to six of ballast. The whole was then turned out and mixed together in the ordinary way, the cube yard taking about 10 gallons of water. The whole bulk would stand as follows:—

Ballast		27	cubic feet.
Lime	$4\frac{1}{2}$	$\left.\right\} 10\frac{1}{2}$	"
Water	6		
Total		$37\frac{1}{2}$	"

"The concrete thus mixed was thrown into the box from the level of the ground, so that the lower part would have a fall of about 4 feet, and the upper part of 1 foot. The experiment was also made of throwing it from a platform 10 feet above the ground. In each case the result was the same, viz., the whole mass made into concrete occupied the same space as the dry ballast, 1 cubic yard; all the bulk of the lime and water, being about two-fifths of that of the ballast, was lost. The surface was carefully levelled and thin boards tacked over, so as to ascertain

whether there were any expansion in the setting, but none could be perceived."

Probably the ballast with which these experiments were made was very wet, at any rate most people accustomed to building pursuits know that the result in an ordinary way is just the reverse. Mr Goodwin, a builder, who erected a number of concrete warehouses and industrial dwellings in Southwark Street, London, in a communication to the *Builder* in 1869, says:—

"It has to be borne in mind that a yard of concrete mixed dry, when wetted and put into the apparatus, falls considerably short of a yard—at least 15 per cent. Neither does the cement make bulk, but disappears in measuring, as does the water."

Messrs Lucas, the extensive contractors, also wrote:—

"The following experiment was made at the new Italian Opera House, Covent Garden; a deal box measuring 3 feet by 3 feet, and 3 feet deep, carefully made for the purpose, was placed upon a wood floor, and filled with ballast thrown in from a shovel and made quite level with the top. The ballast was then taken out and mixed in the usual manner (upon the wood floor) with 3 bushels of stone lime, and thrown again with shovels into the measure whilst hot; the concrete when first put in exactly filling the measure, as did the ballast before being mixed with the lime. A deal measure was used in order to ascertain if any expansion took place, but as it retained its shape, none occurred horizontally, nor did any appear vertically. The experiments were made with gravel taken from the excavations, well screened, and with unscreened Thames ballast, the same quantity of lime being used to each, and the operation performed alike in both cases. When set, the concrete formed with the screened gravel had diminished in height about 1½ inch or one-twenty-fourth, and that formed of Thames ballast unscreened, about 2¼ inches, or one-sixteenth. We think, however, that had the concrete been thrown in from a stage, the subsidence would have

been greater, most probably one-twelfth, and we should not think it safe in making an estimate to calculate the subsidence as less than one-twelfth."

Messrs Cubitt & Co., of Gray's Inn Road, stated that from actual experiment they found that 5,722 cubic yards of Thames ballast made 4,891 cubic yards of concrete. It was thrown from a height of 10 feet. The quantity of ground stone lime consumed was 544 cubic yards. The loss in this instance appears to have been a little over one-seventh—a considerably larger proportion than resulted from Messrs Lucas's trials. It is possible with so large a quantity that the measurement of the ballast was not accurately determined. Perhaps the carts held the correct measurement when loaded, but the jolting on their way to the works may have considerably reduced the bulk.

Mr G. Robertson, resident engineer for the construction of Leith Docks, said:—

"When the ballast was moderately dry, 12 cubic yards of ballast and 2 cubic yards of fresh ground lime made 11 cubic yards of concrete mixed and deposited, but if the ballast was very dry, the same quantity would make only 10 cubic yards, and *vice versa*. The first quantity, however, is the average of thousands of yards, and may be depended upon as accurate in practice, with the above proportion of lime."

This gives the loss as between one-sixth and one-twelfth, the difference resulting entirely upon the condition of the ballast as to dryness.

The diminution in bulk of the materials used for making concrete depends very much upon the nature of the aggregate, its compactness and solidity, or the reverse; wet fine gravel, or sea beach, for instance, would sustain very little reduction in volume by compression, whereas dry burnt clay or brick débris, capable of absorption and composed of materials of all shapes and sizes, would, on the application of water, have its smaller particles through the motion of the water and their increased weight from

absorption, forced between those next in size, and so on upward until what was a loose, hover material, is turned into a solid, compact one. In this case the original volume would be much reduced. In a general way never less than one-sixth of the void to be filled, or one-sixth of the net measurement of the work when executed, should be added thereto, and accepted as the amount of aggregate needed when no packing is employed. This may be thought an excessive proportion, but when the material has to be carted a considerable distance, and is measured into the carts and not on delivery, there is always a certain amount of waste, and bare measurement is more the rule than full.

CHAPTER XXII.

SUGGESTED SPECIFICATION FOR CONCRETE.

INDIVIDUAL opinion and surrounding circumstances necessarily prevent any standard specification being generally adopted, but one of a suggestive character may be useful to a certain extent.

FOUNDATIONS.

The concrete to be composed either of Thames ballast, clean pit gravel, crushed flints, hard stone chippings, refuse stone from quarries or masons' yards, slag from iron ore, furnace clinker, brickyard or pottery refuse, or any similar material, hereafter called the aggregate, which must be of a hard and unyielding character, and samples of a fair average with the bulk to be approved before delivery upon the site.

The matrice or cementing material to be of Portland cement, to the British Standard Specification.

The aggregate to be, so far as is practicable, varied in size, no portion being larger than would pass through a 2½-inch cross mesh sieve, nor smaller than Thames sand. The particles to be of angular shape, free from clayey, loamy, or argillaceous matter, and while a sufficient proportion of coarse sand shall form a constituent, it must not exceed such amount as would tend to weaken the character of the concrete. If necessary to break the aggregate, it must be done by a stone crusher, and breaking with a hand

stone hammer will only be permitted for occasional purposes. If the aggregate is not perfectly clean it must be well washed previous to or at the time of use.

The cement to be shot out of the casks or sacks, on a wood tongued floor removed from the natural soil to prevent absorption of moisture therefrom, in a building—weather boarded preferred—perfectly impervious to moisture and not covered with galvanised iron by reason of a possibility of condensation thereon, and as a result the dripping of water on the cement.

The cement to be delivered on the works at least two weeks before being required for use, and occasionally stirred to allow its particles to slake and cool, unless it is delivered in sealed bags from an approved manufacturer, and the manufacturer's guarantee that it has been tested and conforms in all respects to the British Standard Specification is sent with every consignment, in which case it can be used direct from the sacks and with no delay, if desired. In any case samples are to be tested whenever required at the contractor's cost.

The cement shed is not to be used as a mess room, store place, workshop, or for any purpose whatsoever except for keeping cement therein.

Packing will be allowed on the following conditions:—It must be a clean, hard, and imperishable material; no old smoky bricks from chimneys, or old stone upon which is lichen or other vegetable growth, or venty stone, or condemned materials more or less disintegrated will be allowed, but such packing must be sound, hard, clean, and shapeable. No packing must approach nearer than 2 inches of the inside or outside face of foundations, nor shall any two pieces of packing be a less distance than 5 inches from each other. If of irregular form, the largest side is to be placed downward and be rubbed or embedded into the concrete, so that adhesion may be secured and no cavities be occasioned in the foundations. There shall be a layer or course of concrete 9 inches in thickness between packing

courses, measuring from the top of the highest packing piece.

For mixing the ingredients, platforms or mixing boards not less than 10 feet square are to be used, and as many as may be necessary.

The proportion of matrice to aggregate shall be one part of the former to ten of the latter, and this proportion shall be ascertained by means of boxes or measures to contain the respective quantity of each, unless the matrice is delivered in sealed bags and used direct, the weight of a bag being ascertained and the correct proportion of aggregate measured in a box of the proper dimensions. The cement to be weighed by preference to being measured, if arranged.

The necessary amount of water cannot be specified ; this must depend upon the nature of the aggregate, but no more shall be used than is actually required to cause the matrice to adhere to the aggregate, and become of a moderate sloppy character.

If the aggregate is of a porous character it is to have water thrown over it previous to the mixing, and as much as may be necessary to thoroughly indurate it.

The ingredients are to be turned over twice dry and twice wet, by not less than four men, one of whom shall use a two-pronged hook or rake to aid in thoroughly incorporating the mass, and another add the water gradually by means of a watering-pot with a rose fitted thereto. The materials to be kept moving during the time the water is being added, to prevent the cement (being the finer portion) sinking away from the coarser.

Not more than 1 cubic yard of concrete shall be mixed at a time, and not less than 18 inches in depth or thickness of concrete shall be deposited at a time ; when work is about to be suspended for the day, the concrete shall be stopped off by means of a board, and not left in a loose condition at the ends ; as great a length of the trenches as is possible shall be filled in at a time.

When concrete is about to be laid on other concrete

which has been previously deposited in the trenches, the surface of the latter shall be cleansed by throwing buckets of water thereon, and which will also assist in causing cohesion between the two layers.

If the bottom of the trench is sloppy or muddy from rainfall or other causes, as much as possible of the mud and water shall be removed, and 3 inches in depth or thickness of dry core or aggregate free from fine portions shall be laid thereon, previous to the deposition of concrete; if the sides are loose or liable to crumble, boards shall be placed against them, to prevent dirt becoming intermixed with the concrete.

If practicable the concrete shall be tipped in from barrows at a height not exceeding 4 feet, and where levelling takes place it is to be rammed or beaten with a wood beater of suitable dimensions.

The concrete is to be covered up as the work progresses with boards, corrugated iron sheets, or any other material which will protect it from frost, from sun rays, and from being washed by rain, and shall remain so covered for not less than two consecutive days.

Floors and Roofs.

The general conditions as to the nature, &c., of the aggregate and the matrice, and the general treatment to apply to floors and roofs with the following exceptions:—The aggregate is to be furnace ashes, coke breeze, or ashes and coke breeze mixed, crushed brick débris, or similar materials, but none larger than would pass a 1¼-inch mesh sieve, and intermediate sizes down to coarse sand. No packing to be used, and the concrete deposited in a mass, not in layers, and gently tamped or beaten at the time it is being deposited with a tamper or beater about 8 or 10 inches square. The concrete is not to be left incomplete between the walls, joists, or other supports when work is suspended each night, but to be stopped off with a board

in the centre of all intermediate supports. No two grades of concrete to be used but only the one specified.

A long straight-edge shall be used to properly straighten the surface of the concrete as it is being deposited in place.

The proportion of materials shall be one to five by measure.

The amount of water to be less than used for foundations and less sloppy in character.

After it has been deposited in place one day in summer and two days at other times, or at a greater interval if the cement is of a slow-setting character, it is to be grouted with sand and cement, one to one, well worked in with a broom.

No packing to be used.

The concrete is to be covered up with tarpaulins or sacks, or other suitable protection if rain is imminent.

It is unnecessary to tip or throw the concrete from a height, but by preference should be deposited gently from buckets or barrows.

Batches of concrete are not to be mixed and left on the mixing boards during ordinary meal times.

CHAPTER XXIII.

TABLES AND MEMORANDA.

THE following tables and memoranda may be found useful in estimating the weight, proportions, &c., of concrete materials.

Aggregates made from brickyard débris or broken stone should be, as a matter of course, the same weight as when whole, except that 1 cubic yard of stone in the block would measure nearly 1¼ cubic yard of aggregate when broken into fragments. It would be safe to assume, however, that the weight of concrete made from any material of a suitable consistency, with the addition of Portland cement as a matrice, would approximate closely —measure for measure—to the weight of the material in a solid form, *plus* the amount of water required to mix the two.

As the requisite quantity of water depends entirely upon the amount of absorption possessed by the aggregate, and the purpose the concrete is for, no quantity can be stated with accuracy; but Mr Carey, engineer of the Newhaven breakwater and harbour, found that for the concrete used in their construction, and for which gravel was used as an aggregate, an average of 22 gallons of water was necessary to mix a cubic yard of concrete; this would add 220 lbs. to the weight of the dry materials. Eventually, no doubt, the concrete becomes of nearly the same weight as the aggregate and matrice combined previous to being mixed to form concrete. Where Portland cement is used as a matrice, the weight of the aggregate and matrice

combined, sufficient to make a cubic yard of concrete, would be approximately as follows :—

Approximate Weight of Concrete Materials.

If the matrice is Portland cement and the aggregate is made from—	Weight per cubic yard of Concrete Materials. Ton.	Cwt.
Granite	1	19
Kentish rag	1	18
Fire-brick	1	16
Portland stone	1	15
Chalk flint and surface flint (varies)	1	15
Slag from iron ore (varies)	1	10
Bath stone	1	9
Thames ballast	1	7
Pit gravel (varies)	1	7
Brick débris (varies)	1	6
Burnt clay (varies)	1	4
Furnace clinker (varies)	1	3
Coke breeze	...	14

To ascertain the approximate weight of concrete materials including water required for mixing the same, add 2 cwt. per cubic yard to above.

Water Memoranda.

A gallon of water weighs 10 lbs.
224 gallons weigh a ton.
1 cubic foot of water contains $6\frac{1}{4}$ gallons.
1 „ yard „ „ 168 „

Solid Measurement.

2 gallons = 1 peck.
8 „ = 1 bushel.
21 bushels = 1 cubic yard.
27 cubic feet = 1 „

Dimensions of Vessels for Measuring Concrete Materials.

A box or rectangular measure to hold a cubic yard of an aggregate, or 21 bushels, should measure, internally, 4 feet long, 3 feet wide, and $2\frac{1}{4}$ feet deep.

Or, to hold $\frac{2}{3}$ cubic yard, equal to 18 cubic feet, or 14 bushels, the

internal dimensions should be 4 feet long, 3 feet wide, and 1½ foot deep.

The internal dimensions of a rectangular box or measure to hold the correct proportion of the matrice for 1 cubic yard of the aggregate should be approximately:—

When the proportion is

1 to 7	- - -	20	by	20	by	16⅝	inches.
1 " 8	- - -	20	"	20	"	14⅝	"
1 " 9	- - -	20	"	20	"	13	"
1 " 10	- - -	18	"	18	"	14⅜	"
1 " 11	- - -	18	"	18	"	13⅛	"
1 " 12	- - -	18	"	18	"	12	"
1 " 13	- - -	18	"	18	"	11 1/16	"
1 " 14	- - -	18	"	18	"	10⅜	"

The dimensions of a rectangular box or measure to hold the correct proportion of the matrice, for ⅔ cubic yard of the aggregate, should be approximately:—

When the proportion is

1 to 7	- - -	18	by	18	by	13¾	inches.
1 " 8	- - -	18	"	18	"	12	"
1 " 9	- - -	18	"	18	"	10 11/16	"
1 " 10	- - -	18	"	18	"	9⅝	"
1 " 11	- - -	18	"	18	"	8¾	"
1 " 12	- - -	16	"	16	"	10⅛	"
1 " 13	- - -	16	"	16	"	9¼	"
1 " 14	- - -	16	"	16	"	8 11/16	"

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